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# Microbiological Quality Assessment of Ready-to-Eat Foods in Urban Markets: A Public Health Perspective

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**Abstract**

The safety of ready-to-eat (RTE) foods in urban markets remains a pressing public health concern, particularly in low- and middle-income countries, where informal food vending is prevalent. This study critically examines the microbiological quality of RTE foods sold in urban markets, identifying key contamination pathways, assessing associated health risks, and proposing actionable strategies for improvement. Guided by a structured conceptual framework, the research synthesizes global and regional literature, with emphasis on African contexts, including Nigeria and Ghana, to provide a nuanced understanding of the sector.

The review identifies contamination at both pre- and post-processing stages, aggravated by inadequate sanitation, poor vendor hygiene, improper storage, and insufficient cold chain infrastructure. Distribution and retail environments, coupled with climatic variables such as rising temperatures, humidity, and flooding, further amplify microbial risks. Common hazards include Escherichia coli, Salmonella spp., Listeria monocytogenes, Staphylococcus aureus, and mycotoxin-producing fungi—agents responsible for acute gastrointestinal illness and, with persistent exposure, chronic conditions such as cancer, immune suppression, and antimicrobial resistance.

The study highlights significant public health and socio-economic burdens arising from unsafe RTE foods, including high treatment costs, loss of productivity, and diminished consumer confidence in food systems. It emphasizes that vendor practices, consumer awareness, and community engagement play pivotal roles in risk reduction, with evidence from behavior change campaigns and branded safety certification schemes demonstrating positive outcomes.

In conclusion, ensuring the microbiological safety of RTE foods demands an integrated approach: rapid detection technologies, environmental monitoring programs, targeted vendor training, infrastructural support, climate-resilient food safety frameworks, and sustained public education. Recommendations advocate for multi-stakeholder collaboration among regulatory authorities, food businesses, academia, and consumers to foster a robust food safety culture that is both sustainable and contextually relevant.

**Keywords:** Ready-to-Eat Foods, Microbiological Quality, Food Safety, Public Health, Urban Markets, Vendor Hygiene

## 1. Introduction

In the wake of rapid urbanization, bustling city markets across the globe have become pivotal hubs for the proliferation and consumption of ready-to-eat (RTE) foods. These consumables—encompassing street-vended snacks, packaged salads, and quick meals—offer convenience and affordability but also constitute an elevated microbiological risk. The epidemiological burden of foodborne illnesses remains pronounced; the World Health Organization estimates that in 2003, roughly 600 million cases of foodborne disease occurred globally, resulting in 420,000 deaths, underscoring the critical need for surveillance of RTE foods in urban settings (World Health Organization, 2003) [61].

Scientific investigations spanning diverse geographical contexts have increasingly spotlighted the microbiological quality of RTE foods. In Europe, Arienzo *et al.* (2020) [7] evaluated leafy green salads retailed through supermarkets, uncovering significant bacterial proliferation during both shelf-life and home refrigeration, especially in medium- and high-cost products. These findings signal that even within regulated retail environments, temperature abuse and inadequate packaging can undermine microbial safety. Similarly, in East Asia, Ng (2013) [33] revealed substandard microbial loads in Siu Mei (Chinese barbecued pork) sold through licensed vendors in Hong Kong, pointing to persistent contamination risks even under formal

retail licensing.

Emerging evidence from low- and middle-income countries (LMICs) underscores how infrastructural and regulatory gaps amplify microbiological risks. In a recent review, Lawal *et al*. (2023) synthesised findings on enteric pathogens in ready-to-eat fresh produce, identifying poor water quality, environmental contamination, and inadequate food handler hygiene as dominant pathways for microbial transmission (Lawal *et al*., 2023).Parallel field studies in African urban contexts corroborate such concerns. In Nigeria, Saka, Ahmad, and Abubakar (2022) [43] assessed RTE vegetables in Kano's Yankaba Market, revealing heavy bacterial loads: Escherichia coli and Staphylococcus aureus predominated among isolates, alongside fungal contaminants including Aspergillus species, collectively indicating a high risk to public health. More recently, Makinde *et al*. (2023) [29] analyzed diverse RTE food items across Lagos markets, appraising not just bacteriological counts but also the presence of biotoxins, thereby underscoring a dual microbial and toxin-based health hazard.

Further investigation in Nigerian university environs corroborates these concerns. Ajiboye, Alabi, and Hammed (2023) [5] assessed the bacterial quality of ready-to-eat snacks sold in restaurants within the Federal Polytechnic Offa, Kwara State, and found widespread contamination with pathogens—indicating that even academic-adjacent food settings frequently fall short of microbiological safety standards.These regional assessments align with cross-national research; Mengistu (2022) [31] systematically reviewed data from several developing countries, documenting both elevated pathogen prevalence in street-vended RTE foods and endemic lapses in food handler hygiene. The public health ramifications are considerable, as studies like Sabuj (2020) [42] conducted quantitative microbial risk assessments on RTE fast foods, concluding that consumption posed substantial infection risk due to pathogen loads exceeding safety thresholds.

At an institutional level, school feeding programmes in Ethiopia illustrate broader systemic vulnerabilities in RTE food preparedness. Lautze *et al*. (2003) [27] emphasise that underlying risk factors—including inadequate infrastructure, limited resources for safe food handling, and insufficient oversight—create conditions in which contamination can occur despite the presence of food provision schemes. These systemic weaknesses heighten vulnerability among school-aged children, particularly when access to safe water, hygienic preparation facilities, and proper storage is constrained (Lautze *et al*., 2003) [27].This context points to the need for more stringent quality control across diverse RTE supply chains. Meanwhile, Giwa (2021) [19] conducted hand-swab analyses of food handlers in market settings, documenting microbial growth in over 96% of samples—including E. coli, Shigella, and Klebsiella species—thereby illustrating the critical role of hygiene in mediating contamination.

Together, these global and regional findings converge on the urgent imperative to systematically assess microbiological quality of RTE foods in urban markets, integrate public health frameworks into food safety protocols, and inform intervention strategies. The urban context presents a complex interplay of environmental exposure, informal vending, regulatory slack, and consumer demand, calling for a public-health-centric lens to microbial surveillance and mitigation.

This study aims to comprehensively evaluate the microbiological quality of ready-to-eat foods sold in urban markets, situating the analysis within a public health perspective. Its primary objective is to quantify levels of bacterial, viral, and fungal contamination in RTE food items, identify predominant microbial hazards, and assess associated health risks. The scope encompasses a comparative, cross-sectional assessment across representative urban market sites, incorporating both vendor hygiene practices and environmental conditions. By integrating rigorous laboratory testing with observational vendor surveys, the study seeks to delineate the critical control points across the RTE food supply chain. Geographic coverage includes diverse market types—open-air street vending, university precincts, and indoor retail outlets—providing a holistic representation of urban food systems. Ultimately, findings will inform food safety policy, capacity-building interventions among stakeholders, and evidence-based strategies to reduce foodborne disease in urban populations.

## 2. Framework for Understanding Microbiological Quality in RTE Foods

The microbiological quality of ready-to-eat (RTE) foods is shaped by a confluence of dynamic factors encompassing the nature of the product, environmental context, handling practices, and technological interventions. RTE foods are consumed without further treatment, placing them at elevated microbiological risk when pathogenic organisms such as Listeria monocytogenes, Salmonella spp., or Escherichia coli remain viable within the supply chain (World Food Safety Organization, 2021) [60]. These microbial hazards can proliferate rapidly in the absence of effective barriers, elevating the stakes for public health surveillance.

Studies in high-income contexts underscore this challenge. Arienzo *et al*. (2020) [7] revealed that ready-to-eat leafy green salads sold in Italian supermarkets exhibited significant growth in aerobic mesophiles and E. coli over shelf life and during home refrigeration, despite packaging interventions. Indeed, medium- and high-cost products displayed higher microbial increases, likely due to packaging methods such as modified atmosphere that inadvertently foster microbial proliferation (Arienzo *et al*., 2020) [7]. Similarly, in Brazil, de Oliveira *et al*. (2011) [16] documented substantial aerobic and Coliform loads in minimally processed RTE salads, even within regulated retail contexts, suggesting that microbial control demands more than standardized industrial protocols.

Innovative methods such as non-invasive spectral sensing offer promise for real-time microbial surveillance. Tsakanikas *et al*. (2019) developed a unified spectral analysis workflow to noninvasively estimate microbial contamination in green salads, demonstrating robust correlations between spectral signatures and microbial counts under isothermal and dynamic temperature conditions. This approach highlights the need for technological integration into supply chain monitoring for early detection and intervention.

At the institutional level, cafeterias in public universities exemplify how handling environments mediate microbial quality. Giwa *et al*. (2021) [19] conducted microbiological surveys of RTE foods and preparation surfaces in such

settings, identifying pervasive contamination by E. coli, Staphylococcus aureus, and other opportunistic pathogens across both food items and preparation areas. Their findings reaffirm that human-driven hygiene lapses significantly contribute to contamination, regardless of geographic or economic context.

In sub-Saharan Africa, the framework must account for both infrastructural constraints and cultural culinary practices. Profit *et al*. (2021) [40] reviewed RTE salads and fresh vegetables across Nigeria, observing 100% bacterial isolation rates—including E. coli, Salmonella, and Staphylococcus aureus—with contamination reflecting deficiencies in washing water quality, preparation environments, and handling protocols. Similarly, Alegbeleye *et al*. (2023) [6] reported high microbial loads in coleslaw samples at restaurants in Ibadan, Nigeria, indicating that even indoor, ostensibly controlled settings are vulnerable to significant microbial hazards.

Further highlighting the multifaceted nature of contamination, Beshiru, Okoh, and Igbinosa (2022) [11] characterized RTE foods sold in Yenagoa, southern Nigeria, identifying a high prevalence of diarrheagenic E. coli, many of which displayed multidrug resistance and virulence factors such as curli and cellulose formation. This scenario emphasizes that RTE foods are not merely vectors of contamination but also potential reservoirs of antimicrobial resistance, amplifying public-health risks.

Expanding the lens across Africa, Tonjo, Manilal, and Seid (2022) [50] examined the bacteriological quality of ready-to-eat raw minced meat from hotels and restaurants in Arba Minch, Ethiopia, reporting elevated total viable counts and significant coliform presence. Their findings demonstrate how traditional preparation practices, ambient-temperature storage and vending, and inadequate cold chain infrastructure contribute to heightened microbial risks in resource-constrained urban contexts. Lautze *et al*. (2003) [27] similarly highlight, in the context of Ethiopia, that vulnerabilities in institutional food provision—such as inadequate handling practices, storage limitations, and intermittent lapses in quality control—can compromise food safety. Such systemic challenges are particularly pronounced in settings like school feeding programmes, where resource constraints and infrastructure gaps intersect with high demand, increasing the likelihood of safety threshold breaches (Lautze *et al*., 2003) [27].

Together, these global and regional studies converge on several core dimensions of the microbiological quality framework for RTE foods: intrinsic susceptibility due to consumption without reheating, microbial growth facilitated by storage and packaging conditions, contamination introduced through handling and inadequate sanitation, technological limitations in detection, and contextual challenges such as infrastructure deficits or inadequate cold chains. Surveillance strategies must thus be multifactorial—integrating advances in rapid detection, robust hygiene training, and environmental controls.

In high-income countries, adoption of damage prevention systems—including HACCP, GMP, environmental monitoring, and rapid microbial testing—has enhanced RTE safety (World Food Safety Organization, 2021) [60]. Yet challenges remain, especially in informal or street-vended environments where oversight may be limited. Therefore, frameworks developed for LMICs must adapt these principles to context-appropriate models. Combining low-cost microbial testing, community education, and simple technologies such as point-of-care sensors could offer sustainable avenues for improving microbial safety in RTE supply chains.

### 2.1 Ready-to-Eat Foods in Urban Marketplaces

Ready-to-eat (RTE) foods have become an integral component of urban dietary landscapes across both high- and low-income settings, providing accessible meals for diverse populations including students, working adults, and transient commuters. Through a confluence of convenience, affordability, and evolving consumer lifestyles, their prevalence in marketplaces and informal sectors continues to expand significantly. In Ghana, for instance, a study of street-vended vegetable salads in Tamale's central business district revealed disturbingly high levels of microbial contamination, with Escherichia coli detected in 96.7% of samples, Bacillus cereus in 93.3%, Salmonella spp. in 73.3%, and Shigella spp. in 76.5%, underscoring the vulnerability of urban RTE foods when hygienic practices are inadequate (Abakari *et al*., 2018) [1]. These findings reflect broader patterns: RTE food items, often prepared in makeshift settings lacking adequate sanitation or temperature control, are particularly susceptible to pathogenic exposure.

Further investigation in university-adjacent food environments reinforces this concern. Ajiboye, Alabi, and Hammed (2023) [5] conducted a bacteriological assessment of ready-to-eat foods—specifically white rice, beans, and MoiMoi—served in campus canteens at the Federal Polytechnic, Offa, Kwara State, and uncovered elevated counts of Staphylococcus aureus, Escherichia coli, Salmonella, and Shigella species. These findings affirm that even academic settings are not insulated from microbiological safety lapses (Ajiboye, Alabi& Hammed, 2023) [5].

At a macroeconomic level, ready-to-eat foods represent a rapidly expanding global market, illustrating the industrialisation of convenience foods. According to global-market analyses, the RTE food sector is expected to double—from approximately USD 194 billion in 2024 to over USD 407 billion by 2034—driven by mounting consumer demand, technological packaging advancements, and shifts toward premium and health-oriented products (Market, US, 2024). While this expansion principally pertains to packaged items in supermarkets, the trend undeniably influences broader consumer expectations and trajectories across urban food systems, catalysing parallel growth in both informal street-vended RTE products and industrially prepared alternatives.

Microbiological surveys in developed settings provide contrasts that nonetheless affirm risk persistence. A multisite investigation across retail environments found frequent occurrences of bacterial contamination at various points of processing and sale, including high aerobic counts and the occasional presence of pathogens, indicating that RTE foods—even when subjected to regulated industrial processes—retain risk potential if control measures are inadequate (Wang *et al*., 2020) [57]. Complementing these findings, emerging technologies such as non-invasive spectral sensing are being developed to rapidly assess contamination in RTE salads, though their application remains largely experimental (Tsakanikas *et al*., 2019). These innovations point toward the future of microbial risk

monitoring, but currently are far from widespread deployment in resource-limited urban contexts.

Within Nigeria, meta-analytical data from Bayelsa State reinforce the urgency of addressing microbial threats in urban RTE items. Izah *et al*. (2022) [22] conducted a comprehensive analysis across multiple studies, revealing striking contamination trends: microbial loads frequently surpassed acceptable limits, and pathogens such as Salmonella, E. coli, and Staphylococcus aureus were commonly implicated. These patterns echo similar narratives across street-vended and institutional RTE markets, collectively emphasising the ubiquity of microbial challenges in urban food provisioning systems.

Beyond Nigeria and Ghana, studies across sub-Saharan Africa further elucidate the public health nexus. In Uganda, Rutaro *et al*. (2024) examined hygiene and value chain practices in street-vended grasshopper-based RTE snacks, identifying multiple points of contamination from processing through vending, and underscoring how traditional RTE foods within urban and peri-urban settings remain critically under-sanitised. Furthermore, investigations in Cameroon's Douala schools established that RTE foods sold within educational environments pose meaningful health risks, with bacterial pathogens detected in a substantial share of meals and predominantly poor hygiene practices among vendors (Ngueugang *et al*., 2021) [34].

### 2.2 Pathways of Microbiological Contamination

Urban marketplaces serve as dynamic nodes where demographic diversity, time constraints, and economic considerations converge to foster a robust demand for ready-to-eat (RTE) foods. These foods—ranging from salads and rice dishes to sandwiches and local specialties—are frequently prepared in environments that prioritize convenience and affordability over comprehensive hygiene, creating inherent food safety vulnerabilities. This section critically examines the ubiquity of RTE foods in urban contexts, explores the drivers of their popularity, and highlights the microbiological risks these trends engender across varied settings.

In many developing urban centers, RTE foods are integral to daily sustenance due to their accessibility and low cost. In Tamale, Ghana, Abakari *et al*. (2018) [1] found that 96.7% of street-vended vegetable salad samples were contaminated with Escherichia coli, while Bacillus cereus, Salmonella spp., and Shigella spp. were detected in over 70% of samples, respectively—underscoring the persistent public health threat posed by these food items (Abakari *et al*., 2018) [1]. Similarly, in Nigeria, Ajiboye, Alabi, and Hammed (2023) [5] reported high microbial loads in ready-to-eat foods such as white rice, beans, and MoiMoi sold within the Federal Polytechnic, Offa, Kwara State, with Staphylococcus aureus isolated from more than half of the samples and Escherichia coli detected in nearly one-quarter—underscoring that institutional proximity does not inherently ensure microbial safety (Ajiboye, Alabi& Hammed, 2023) [5].

Urban RTE consumption also thrives in more regulated contexts, yet risks remain evident. Kariuki (2018) [24], in a study of street foods sold in Githurai and Gikomba markets in Kenya, found that a substantial proportion of sampled foods failed to meet bacteriological safety standards. The research highlighted the presence of pathogens such as Escherichia coli and Staphylococcus aureus and identified poor hygiene practices, inadequate storage, and environmental exposure as contributing factors. These findings demonstrate that even where regulatory frameworks exist, they may not fully mitigate the inherent risks associated with ready-to-eat foods (Kariuki, 2018) [24].

Delving into underlying contamination pathways, Wang *et al*. (2020) [57] undertook a multisite survey in varied processing and retail environments, revealing pervasive bacterial contamination across different points in the RTE food supply chain. Their findings emphasize that microbial hazard can be introduced at the production stage, persist through handling, and escalate at vending points—underscoring the necessity for comprehensive monitoring of the full value chain (Wang *et al*., 2020) [57].

Globally, concerns about emerging RTE foods are mounting. The World Health Organization (2023) [63] outlines comprehensive guidance on the prevention and control of microbiological hazards in fresh fruits and vegetables, emphasising waterborne pathogens, inadequate post-harvest handling, and cross-contamination as critical risk factors—thereby underscoring systemic vulnerabilities that extend from primary production through to marketplace distribution (World Health Organization, 2023) [63]. Du Plessis *et al*. (2021) [17] provide insights from a high-income context, showing that microbial contamination of fresh produce can occur at multiple points along the supply chain—from farming to retail—and that breaches in safety standards are not confined to low-resource settings. Their investigation into water pollution and its role in introducing pathogens such as Escherichia coli and Listeria monocytogenes highlights that even well-regulated markets face persistent RTE food safety challenges when contamination vectors are not effectively managed (Du Plessis *et al*., 2021) [17].

Technological advancements are emerging as potential risk-mitigation tools. Tsakanikas *et al*. (2019) demonstrated a novel non-invasive spectral sensor approach to estimate microbial loads in salads by correlating spectral patterns with microbial proliferation under controlled temperature fluctuations. Such innovations portend scalable, low-cost surveillance modalities capable of early hazard detection (Tsakanikas *et al*., 2019).

Elsewhere in Africa, investigations within formal institutional environments—such as schools in Cameroon—have detected pathogens in RTE items, with vendors frequently exhibiting inadequate hygiene awareness and personal cleanliness. Ngueugang *et al*. (2021) [34] reported frequent contamination in meals served within primary school settings, indicating that structured settings can inadvertently perpetuate microbiological risks when food safety protocols are absent (Ngueugang *et al*., 2021) [34].

These cross-contextual analyses converge on several critical insights. First, the omnipresence of RTE foods in urban landscapes—embodied by marketplaces, street vendors, institutions, and retail outlets—reflects both consumer demand for convenience and structural inadequacies in sanitation, regulation, and infrastructure. Second, microbial contamination is often systemic and multifaceted, involving factors from raw materials to handling environments, packaging techniques, and storage conditions. Lastly, innovative interventions—ranging from sensor-based detection systems to structured training and rigorous surveillance—are vital for reducing foodborne disease incidence and safeguarding public health.

### 2.2.1 Contamination at Source and Processing Stages

The journey of ready-to-eat (RTE) foods from raw materials to the consumer's plate involves multiple stages where microbial contamination can be introduced or amplified. At the initial processing stage, raw produce—whether meats, vegetables, or grains—can harbor pathogens from environmental, animal, or handling sources. Wang *et al.* (2020) [57] conducted a comprehensive multisite survey and demonstrated that RTE foods frequently become contaminated during processing and selling phases, with high bacterial counts found in both pre-packaged and street-vended products. The study emphasizes that contamination is not confined to end-point handling but originates early in the supply chain, thereby demanding rigorous sanitation across all stages (Wang *et al*., 2020) [57].

When considering high-risk pathogens such as Listeria monocytogenes, Kurpas *et al*. (2018) [26] highlighted how RTE meat products are particularly susceptible to contamination within processing plants. Their investigation reveals that the pathogen often persists on equipment surfaces and packaging areas, frequently forming biofilms that resist standard cleaning protocols. Such biofilms serve as persistent contamination reservoirs, leading to widespread distribution of pathogens across multiple product batches (Kurpas *et al*., 2018) [26].

In response to these challenges, technological innovations are emerging as valuable tools for early detection. Tsakanikas *et al*. (2019) devised a novel non-invasive spectral analysis workflow to predict microbial loads in RTE leafy salads. By correlating spectral data with actual microbial counts under both controlled and dynamic temperature storage conditions, the study demonstrated the feasibility of real-time, front-line monitoring—potentially enabling early identification of contamination before food reaches the consumer (Tsakanikas *et al*., 2019).

In many urban LMIC contexts, contamination often originates at the level of small-scale processing, where food safety standards may not be uniformly enforced. Okeke *et al*. (2021) [37] assessed the microbial quality of locally prepared snacks—such as puff-puff, doughnuts, meat-pie, and egg-roll—sold by street vendors in Lagos Mainland, Nigeria. The findings revealed high microbial loads across all samples, including Staphylococcus aureus, Escherichia coli, Klebsiella spp., Salmonella spp., and fungal contaminants. These results reflect vulnerabilities in initial preparation environments—possibly due to suboptimal cooking, inadequate utensil sanitation, or exposure to environmental contaminants during processing (Okeke *et al*., 2021) [37].

The interplay of these findings underscores that contamination at source and during early processing stages is multifactorial. Raw-material origin, equipment sanitation, environmental conditions, and handling practices collectively shape microbial risk. Even in formal industrial settings, pathogens can persist through biofilm formation, while informal vendors face compounded risks due to minimal enforcement of hygiene standards. Novel detection modalities like spectral sensing offer promise, but significant scaling, validation, and cost-effectiveness evaluation remain necessary, particularly for resource-constrained settings.

### 2.2.2 Contamination in Distribution and Retail Environments

Distribution and retail stages constitute critical phases in the supply chain of ready-to-eat (RTE) foods, where microbial contamination can be introduced or intensified, thereby posing substantial risks to public health. These environments—ranging from formal supermarkets and cafeterias to informal street stalls—embody a nexus of risk factors including temperature abuse, cross-contamination, inadequate hygiene controls, and environmental exposures.

Empirical studies demonstrate that even in developed market contexts, RTE foods may become contaminated during retail handling. Wang *et al*. (2020) [57] conducted a comprehensive survey across processing facilities and selling points, revealing that bacterial loads increase significantly at distribution and retail junctures. Their findings indicated that ready-to-eat items such as salads, meats, and snacks often exhibit elevated counts of aerobic mesophiles and coliforms at the point of sale compared to post-processing levels, underscoring that distribution logistics and retail display conditions contribute meaningfully to microbiological risk (Wang *et al*., 2020) [57].

Similarly, Ahmad and Siddiqui (2015) [4] explain that fresh produce sold in markets is highly susceptible to post-harvest contamination during transport and retail, often arising from factors such as moisture accumulation, inadequate temperature regulation, and frequent handling by multiple intermediaries. They further note that cross-contamination from cutting, packaging, or storage surfaces in retail environments remains a persistent route for microbial transfer, particularly where hygiene controls are poorly implemented (Ahmad & Siddiqui, 2015) [4].

In low- and middle-income African contexts, street vending environments amplify risk. Umoh and Afolayan (1999) [54] assessed street-vended foods in Zaria, Nigeria, documenting that vendors commonly re-serve leftover cooked foods without appropriate reheating or storage, and often display products adjacent to refuse or within ambient temperatures conducive to pathogen multiplication. Bacterial contaminants, including Bacillus cereus and Staphylococcus aureus, were prevalent in sold items, indicating that retail stage practices significantly elevate public exposure to pathogens (Umoh & Afolayan, 1999) [54].

Furthermore, in Ghana, Abakari *et al*. (2018) [1] investigated ready-to-eat vegetable salads vended in city centres and found alarmingly high microbial contamination levels. Their study attributed the risk to factors such as prolonged display under ambient conditions, handling with bare hands, lack of protective barriers, and continual replenishment of food without hygienic replenishment practices—each facilitating pathogen proliferation and cross-contamination at the point of sale (Abakari *et al*., 2018) [1].

## 2.3 Influence of Vendor Practices and Food Handler Hygiene

The pivotal role of vendor practices and food handler hygiene in shaping the microbiological quality of ready-to-eat (RTE) foods cannot be overstated; their influence cascades through contamination pathways, safety compliance, and ultimately, public health outcomes. Street vendors, institutional canteen staff, and small-scale RTE

operators all embody critical touchpoints where food safety is either upheld or compromised. Understanding this dynamic offers essential insight for targeted interventions and policy formulation.

In resource-constrained urban environments, inadequate personal hygiene among vendors remains a key contributor to RTE food contamination. A mixed-methods study conducted in Kano metropolis—which compared street food vendors and institutional canteen food handlers—found that personal hygiene knowledge was significantly deficient, particularly among street vendors (only 18.7% exhibited good hygiene knowledge versus 26.0% among canteen staff) (Ibrahim *et al*., 2023) [21]. Observational evidence revealed limited use of protective wear, inconsistent handwashing, and frequent bare-hand contact during serving, which potentially increases pathogen transmission (Ibrahim *et al*., 2023) [21]. These findings underscore the entrenched knowledge-practice gap despite proximity to formal canteen settings.

Parallel investigations in Ghana shed light on similar concerns in informal settings. Street-vended vegetable salads in Tamale exhibited alarmingly high microbial loads, including E. coli, Salmonella, and Shigella—contamination highly correlated with vendor practices such as inadequate washing, poor handling, and prolonged exposure to ambient conditions (Abakari *et al*., 2018) [1]. These practices facilitate pathogen proliferation, with little or no mitigation instituted at the point of sale (Abakari *et al*., 2018) [1].

On a broader geographic scale, Samapundo *et al*. (2015) [44] assessed food safety knowledge and behaviour among vendors in Port-au-Prince, Haiti, and found that while vendors generally understood contamination principles, this did not consistently translate into safe handling. Observations revealed frequent instances of unsanitary equipment and neglect of fundamental hygienic practices during food preparation and service, indicating the knowledge-practice divide is universally observable across contexts (Samapundo *et al*., 2015) [44].

In Nigeria, the influence of preparation and handling practices within institutional environments has also been examined. Kassy *et al*. (2024) conducted a comprehensive assessment of food safety across preparation, storage, and serving stages within public food service settings in Enugu. Their findings highlighted sporadic adherence to hygiene protocols, including infrequent use of protective clothing and insufficient utensil sanitization. Even where infrastructural capacity existed, operational practices—particularly during consumption phases—frequently contravened hygiene expectations (Kassy *et al*., 2024).

Consumer perspectives further illuminate the impact of vendor practices. Nordhagen *et al*. (2022) explored how both vendors and consumers in Nigeria perceive and act on food safety. Vendors' attitudes significantly affected handling behaviour and hygiene standards; those prioritising economic returns tended to underrate hygiene importance, while consumer demand for affordable and quick service often capped their willingness to engage in hygienic practices that might extend service time or cost (Nordhagen *et al*., 2022). This economic-versus-safety dichotomy shapes the everyday decision-making ecosystem in which RTE foods are produced and sold.

Recognising the infrastructural and socio-economic barriers confronting food handlers, Adeosun (2023) proposed practice-based strategies to reshape safety norms within Nigeria's informal RTE food vending sector. These approaches emphasise capacity building through context-appropriate training, gradual integration of basic hygienic infrastructure, and regulatory frameworks tailored to the lived realities of vendors—mechanisms designed to foster compliance while avoiding undue strain on livelihoods (Adeosun, 2023).

### 2.4 Key Microbial Hazards Associated with RTE Foods

Ready-to-eat (RTE) foods—which are consumed without further cooking—present distinct microbiological hazards that pose substantial risks to public health. This section critically examines principal pathogens and contamination profiles, grounded in global and African perspectives and aligned with the study's broader focus on urban marketplaces.

Listeria monocytogenes has long been recognized as a formidable threat within RTE food systems due to its adaptability to refrigeration and ability to form resilient biofilms. Chen *et al*. (2003) conducted a landmark survey across the United States and documented L. monocytogenes in about 1.2 percent of tested RTE products, including sushi, deli meats, and salads. The findings emphasize that despite stringent regulation, these products can still harbor the pathogen—and, due to the lack of a subsequent heat treatment, pose serious health risks, particularly to immunocompromised populations (Chen *et al*., 2003). Complementing these observations, the World Health Organization (2022) [60] reported that Listeria monocytogenes continues to pose a significant threat in ready-to-eat (RTE) foods, with contamination levels in some products approaching thresholds linked to listeriosis outbreaks. The report emphasises that the pathogen's ability to persist in food-processing environments and proliferate under refrigeration highlights the ongoing public health risks associated with RTE deli items (World Health Organization, 2022) [62].

Enteric bacteria, particularly pathogenic strains of Escherichia coli, also feature prominently among RTE hazards in developing contexts. Beshiru, Okoh, and Igbinosa (2022) [11] analyzed RTE food samples in Yenagoa, Nigeria, and revealed that 26.7 percent of them harboreddiarrheagenic E. coli. Notably, many isolates displayed multi-drug resistance and carried virulence genes, thereby exacerbating the public health consequences of consumption (Beshiru, Okoh & Igbinosa, 2022) [11]. These findings are consistent with broader reviews—such as Mengistu (2022) [31], which highlight enterobacteria, Staphylococcus aureus, and Salmonella as recurrent pathogens in RTE foods across low- and middle-income settings, underscoring a systemic deficiency in microbiological control in informal food sector chains (Mengistu, 2022) [31].

Seafood-based RTE items further compound this risk. A recent study conducted in Bayelsa, Nigeria, examined ready-to-eat seafood, detecting alarmingly high levels of microbes, including multidrug-resistant Vibrio spp., E. coli, and S. aureus. This study also highlights the widespread occurrence of antimicrobial resistance (AMR) among foodborne pathogens, raising concerns about the selective pressures exerted within food production environments. As Brunn *et al*. (2022) [13] emphasise in their global review, the presence of resistant pathogens in food commodities reflects a critical intersection of environmental contamination and inadequate

processing or handling controls, underscoring the need for integrated monitoring and mitigation strategies (Brunn *et al*., 2022) [13].

Expanding coverage to other African urban environments, Blaise Nguendo-Yongsi (2023) [12] examined food consumption patterns in Douala, Cameroon, and highlighted the significant health risks posed by street-vended ready-to-eat foods. The study revealed that microbial contamination remains widespread, with products such as meats frequently exceeding acceptable safety thresholds and exposing consumers to potential pathogens. These insights reinforce broader narratives of contamination and vulnerability within informal food systems across the continent (Blaise Nguendo-Yongsi, 2023) [12].

Synthesizing global and African data frames, key microbial hazards in RTE foods can be categorized as follows:

- Gram-positive pathogens: Listeria monocytogenes is particularly concerning because of its capacity to survive and proliferate under refrigeration, coupled with its ability to cause severe illness in high-risk groups such as pregnant women, neonates, and immunocompromised individuals (World Health Organization, 2022) [62].
- Enterobacteriaceae: Pathogenic members of the Enterobacteriaceae family, including Escherichia coli, Salmonella, and Campylobacter, are frequently associated with ready-to-eat foods in low- and middle-income countries. As Blaise Nguendo-Yongsi (2023) [12] notes in the context of Douala, Cameroon, these organisms are often detected in informal markets and exhibit antimicrobial resistance, thereby intensifying their public health implications (Blaise Nguendo-Yongsi, 2023) [12].
- Cross-contaminants and emerging resistors: Ready-to-eat foods, including seafood and meats, can act as vehicles for multiple pathogens that increasingly exhibit antimicrobial resistance. Brunn *et al*. (2022) [13] note that resistant strains such as Vibrio and Staphylococcus aureus illustrate a convergence of biological hazard and antimicrobial resistance, thereby necessitating dual intervention strategies that address both contamination control and resistance management (Brunn *et al*., 2022) [13].

The interplay of these hazards underscores that RTE food safety concerns extend beyond individual pathogens to include broader issues of resistance, cross-contamination, and environmental exposure. This recognition reinforces the imperative of comprehensive monitoring, regular microbial surveillance, hygiene training for handlers, and integration of antimicrobial-resistance testing in food safety protocols.

### 2.5 Public Health Consequences of Poor Microbiological Quality

The implications of inadequate microbiological quality in ready-to-eat (RTE) foods extend well beyond isolated illness events, manifesting as systemic burdens on public health infrastructures, economic systems, and communities—particularly in urban contexts where consumption of such foods is high. Unsafe RTE foods catalyse outbreaks, exacerbate endemic disease burdens, and disproportionately impact vulnerable populations, including young children and immunocompromised individuals.

Globally, the burden of foodborne diseases remains immense, with unsafe food estimated to result in 600 million illnesses and 420,000 deaths each year. Children under the age of five disproportionately carry this burden, accounting for nearly one-third of total fatalities. This equates to approximately 33 million disability-adjusted life years (DALYs) lost annually, underscoring the severe societal and economic costs of microbial contamination across food chains, particularly in ready-to-eat (RTE) products consumed without further reheating (Tomasello, 2023) [49].

In Africa, the burden of foodborne disease is particularly severe. Sibanda *et al*. (2023) [47] reviewed the transmission dynamics of Listeria monocytogenes at the food–human interface and highlighted how ready-to-eat foods—including street-vended snacks and traditional delicacies—are recurrent vehicles of exposure. The review emphasised that limited laboratory capacity, weak surveillance systems, and inadequate regulatory frameworks across many African countries constrain timely detection and response, thereby increasing both morbidity and mortality. These systemic deficiencies intensify the public health consequences associated with poor microbiological quality of RTE products (Sibanda *et al*., 2023) [47].

At the national level, Nigeria exemplifies the dual burden of acute and chronic consequences. A meta-analysis by Izah *et al*. (2022) [22] of RTE foods in Bayelsa State reported microbial contaminant prevalence—and by extension, disease risk—substantially higher than acceptable thresholds. The study emphasised that such exposures likely fuel recurrent gastrointestinal illnesses, placing pressure on local healthcare services and burdening families with recurrent treatment costs and lost productivity (Izah *et al*., 2022) [22].

Compounding the microbial risk, Makinde *et al*. (2023) [29] demonstrated that artisanal RTE foods in Lagos—common staples among urban dwellers—frequently contained both pathogenic bacteria and mycotoxins, heightening the potential for combined acute and chronic health effects. Biotoxins, such as aflatoxins, can exert long-term carcinogenic and immunosuppressive effects, while bacterial pathogens may cause immediate gastrointestinal illness (Makinde *et al*., 2023) [29]. The co-occurrence of these hazards underscores a complex threat landscape that extends beyond foodborne illness to broader disease resilience and health integrity.

In Central Africa, Blaise Nguendo-Yongsi (2023) [12] examined food consumption patterns in Douala, Cameroon, and highlighted that ready-to-eat street-vended foods, particularly meats, often exceed acceptable microbial safety thresholds. The study associated these contamination levels with high incidences of diarrhoeal disease among consumers, linking the consumption of unsafe RTE products to adverse public health outcomes such as dehydration and increased reliance on healthcare services (Blaise Nguendo-Yongsi, 2023) [12].

At a conceptual level, Elbehiry (2023) [18] provides a comprehensive framework capturing how microbial contamination in food systems—particularly RTE products—leads to both local and systemic health challenges. Initial effects encompass acute gastroenteritis, food poisoning, and in severe cases, sepsis or hospitalization. Cumulatively, outbreaks result in loss of productivity, economic hardship, and destabilisation of public confidence in food systems. In regions where RTE foods serve as primary dietary sources, compromised quality can perpetuate cycles of malnutrition, stunted growth, and

weakened immune response—particularly among children and low-income urban residents (Elbehiry, 2023) [18].

### 2.5.1 Economic and Social Burden of Foodborne Diseases

The economic and social burdens engendered by foodborne illnesses—particularly in urban ready-to-eat (RTE) food contexts—are profound and multifaceted. In low- and middle-income countries (LMICs), the World Bank estimates that unsafe food costs societies approximately US$95.2 billion per annum in lost productivity and an additional US$15 billion in healthcare expenditures (World Bank, 2018) [59]. These staggering figures delineate that the indirect consequences—such as diminished workforce capacity and disrupted livelihoods—substantially outweigh the direct clinical costs, magnifying the urgency of robust food safety interventions.

Country-level studies offer further granularity on these economic burdens. In Burkina Faso and Ethiopia, van Wagenberg *et al*. (2023) [55] quantified costs associated with three major microbial hazards—non-typhoidal Salmonella enterica (NTS), Campylobacter spp., and enterotoxigenic E. coli (ETEC). In Burkina Faso, the aggregated mean economic burden reached 391 million Int$ (2017), equivalent to 3% of national GNI, while Ethiopia's comparable burden was 723 million Int$, representing 0.9% of its GNI. Notably, productivity losses constituted approximately 70% of these costs, with willingness-to-pay (WTP) to avoid mortality comprising most of the remainder (van Wagenberg *et al*., 2023) [55]. These costs are particularly significant given the tenuous balance of household and national economies in such contexts.

Within Nigeria, the economic burden of foodborne illness is closely linked to consumer behaviour and the realities of informal markets. Makinde *et al*. (2020) [28] highlight that while ready-to-eat (RTE) foods in low- and middle-income countries are often associated with significant microbiological risks, they remain highly valued by consumers for their affordability and accessibility. This paradox means that the costs of foodborne diseases go beyond medical treatment, encompassing erosion of consumer trust and the difficult trade-offs faced by low-income urban populations between affordability and food safety. Such dynamics reflect the complex socio-economic challenges in addressing foodborne risks (Makinde *et al*., 2020) [28].

Across Africa, microbial outbreaks associated with ready-to-eat (RTE) foods continue to highlight the heavy social and health burden they impose. Sibanda *et al*. (2023) [47] observed that Listeria monocytogenes and other pathogens, such as Salmonella and E. coli, are frequently implicated in contamination pathways that heighten consumer exposure, particularly in informal markets. The consequences extend beyond immediate illness and mortality, eroding consumer confidence in local food systems and undermining communal wellbeing. In many instances, affected populations also face stigma, interruptions to economic livelihoods, and greater dependence on healthcare systems—impacts that fall disproportionately on vulnerable and marginalised groups (Sibanda *et al*., 2023) [47].

### 2.5.2 Chronic Health Effects of Persistent Exposure

Persistent consumption of microbiologically compromised ready-to-eat (RTE) foods—especially those contaminated with chemical hazards or bioaccumulative toxins—poses significant long-term health risks that extend well beyond acute gastrointestinal illness. Chronic exposures can invoke cumulative physiological damage, elevate cancer risk, impair developmental trajectories, and trigger immune and metabolic disorders.

Aflatoxins, particularly Aflatoxin $B_1$ ($AFB_1$), exemplify a major chronic foodborne threat. Classified by the IARC as Group 1 carcinogens, prolonged dietary exposure to $AFB_1$ is a well-established causal factor for hepatocellular carcinoma (HCC), especially in synergy with chronic hepatitis B infection and malnutrition (Benkerroum, 2020) [9]. These toxins operate via their epoxide metabolites, which form DNA adducts and induce mutations in oncogenes and tumor suppressor genes—such as p53—fostering carcinogenesis over time (Benkerroum, 2020) [9].

Beyond microbial contamination, chemical hazards such as heavy metals and organic pollutants also pose chronic risks to consumers of ready-to-eat foods. Oyet and Samuel (2020) [39] demonstrated that street-vended foods in Lagos contained residues of toxic elements at levels capable of bioaccumulating and contributing to systemic health effects. Chronic dietary exposure, even at subclinical concentrations, can impair immune function, hinder growth in children, and contribute to neurological and reproductive dysfunction. Their findings highlight that vulnerable groups, particularly infants and adolescents, face heightened risks from such long-term dietary exposures, underscoring the insidious nature of chemical hazards in RTE food systems (Oyet & Samuel, 2020) [39].

Beyond microbial contamination, chemical hazards such as heavy metals and organic pollutants also pose chronic risks to consumers of ready-to-eat foods. Oyet and Samuel (2020) [39] demonstrated that street-vended foods in Lagos contained residues of toxic elements at levels capable of bioaccumulating and contributing to systemic health effects. Chronic dietary exposure, even at subclinical concentrations, can impair immune function, hinder growth in children, and contribute to neurological and reproductive dysfunction. Their findings highlight that vulnerable groups, particularly infants and adolescents, face heightened risks from such long-term dietary exposures, underscoring the insidious nature of chemical hazards in RTE food systems (Oyet & Samuel, 2020) [39].

Though not chemical in nature, microbial hazards can also generate long-term health effects when exposure is recurrent. Blaise Nguendo-Yongsi (2023) [12], in his assessment of food consumption patterns in Douala, Cameroon, reported that ready-to-eat street-vended meats frequently exceeded microbial safety thresholds, with pathogens such as Salmonella, Campylobacter, and coliform bacteria commonly present. While the immediate outcome of such contamination is acute gastrointestinal infection, repeated low-level exposure may contribute to chronic inflammation, disruption of gut microbiota, and immune system alterations—conditions that predispose individuals to metabolic and gastrointestinal disorders (Blaise Nguendo-Yongsi, 2023) [12].

## 2.6 Strategies for Monitoring and Improving Microbiological Safety

Achieving microbiological safety in ready-to-eat (RTE) foods requires a multi-dimensional strategy integrating technological advances, regulatory frameworks, capacity building, and local context adaptation. Effective interventions must encompass both proactive monitoring

and corrective controls spanning from the vendor level up through distribution and retail systems.

Rapid diagnostic methods are transforming microbial surveillance by enabling faster and more precise detection of pathogens. Wang, Zhang, and Tang (2022) [56] review advances in clinical microbiology that have direct applications for food safety, including molecular assays, biosensor technologies, and sequencing-based platforms, which allow near real-time identification of emerging microbial contaminants. These innovations reduce reliance on slow, culture-based approaches and present significant potential for early hazard identification, particularly in resource-limited settings where timely interventions are critical (Wang, Zhang & Tang, 2022) [56].

Yet, technological innovation must be complemented by structured environmental monitoring programs. Mota (2021) [32] underscores the importance of environmental monitoring—tracking sanitation effectiveness via regular sampling of food-contact surfaces, equipment, and ambient surroundings—as a critical aspect of microbial control systems. Embedded monitoring protocols generate actionable data, facilitating predictive interventions before contamination leads to product compromise (Mota, 2021) [32].

Vendor training interventions remain central to sustainable improvements. In SabonGari, Kaduna State, Nigeria, Umar, Mande, and Umar (2018) [53] demonstrated that targeted food hygiene training among street vendors significantly enhanced practice outcomes: good food hygiene rose from 30.9% to 69.1%, and personal hygiene from 8.3% to 92.7%. These results confirm that education is both cost-effective and essential for shifting behavioral norms in informal food sectors (Umar, Mande & Umar, 2018) [53].

Building on these insights, Adeosun, Greene, and Oosterveer (2023) [3] outline practice-based strategies aimed at improving ready-to-eat food vending in urban Nigeria. Their study emphasises interventions such as participatory training, incremental provision of basic hygienic infrastructure, the strengthening of vendor networks, and the adoption of regulatory approaches that are flexible and supportive rather than punitive. This visioning and back-casting approach highlights the value of context-sensitive and collaborative engagement as a pathway to fostering long-term improvements in food safety practices without undermining vendor livelihoods (Adeosun, Greene & Oosterveer, 2023) [3].

Economic dimensions also frame monitoring efforts. The economic burden of foodborne disease in African settings—in particular, Ethiopia and Burkina Faso—amounts to hundreds of millions of international dollars, underscoring the cost-effectiveness of microbial safety strategies (van Wagenberg *et al*., 2023) [55]. Investments in hazard surveillance and vendor training become not only public health imperatives but also economically justified measures that preserve productivity and reduce healthcare and societal losses (van Wagenberg *et al*., 2023) [55].

Finally, central coordination and regulatory oversight remain pivotal. Integrating rapid detection tools, environmental monitoring, and vendor education under a unified food safety governance architecture supports consistency and scale. Elbehiry (2023) [18] notes that multifaceted public health strategies—combining laboratory readiness, surveillance, outbreak response, and stakeholder communication—are essential for containing foodborne threats and reinforcing community trust in food systems (Elbehiry, 2023) [18].

### 2.7 Emerging Research and Innovation in Food Safety

The microbiological safety of ready-to-eat (RTE) foods in urban markets hinges on integrated strategies that combine preventive monitoring, technological innovation, targeted training, and regulatory oversight. Given the absence of a reheating step before consumption, any lapse in safety control at any stage—from production to point-of-sale—poses an immediate risk to public health.

Rapid detection technologies are increasingly vital to modern microbial safety monitoring. Wang, Zhang, and Tang (2022) [56] emphasise that recent innovations—such as molecular assays, biosensor-based platforms, and advanced sequencing technologies—enable real-time detection of pathogens, including Listeria monocytogenes, Escherichia coli, and Salmonella. These tools provide faster and more reliable alternatives to conventional culture methods, which, while accurate, are slow and impractical for dynamic food supply chains. Integrating such technologies into inspection frameworks would allow regulators and vendors to identify hazards at earlier stages, thereby preventing contaminated products from reaching consumers (Wang, Zhang & Tang, 2022) [56].

Environmental monitoring programs (EMPs) further reinforce safety by providing systematic surveillance of processing and retail environments. Mota (2021) [32] explains that EMPs involve regular sampling of food-contact surfaces, non-contact surfaces, air, and water in preparation and storage areas to assess sanitation effectiveness. These programs allow early identification of microbial harborage sites, facilitating corrective action and reducing the risk of persistent contamination in both formal and informal food sectors.

Human capacity remains a defining factor in food safety outcomes. In Kaduna State, Nigeria, Umar, Mande, and Umar (2018) [53] demonstrated that structured hygiene training for street food vendors significantly improved compliance with safe handling practices, boosting personal hygiene adherence from 8.3% to 92.7% and food hygiene from 30.9% to 69.1% post-intervention. These gains underline the value of capacity-building initiatives in transforming vendor behaviours, particularly in informal markets where regulatory enforcement is inconsistent.

Informed by such evidence, Adeosun, Greene, and Oosterveer (2023) [3] present practice-based strategies designed to strengthen food safety within Nigeria's urban ready-to-eat (RTE) sector. Their approach emphasises participatory training tailored to vendor realities, the introduction of accessible sanitation infrastructure, and the promotion of vendor associations to facilitate shared learning and collective responsibility. These interventions are framed to balance public health priorities with economic sustainability, thereby fostering adoption without jeopardising the livelihoods of food vendors (Adeosun, Greene & Oosterveer, 2023) [3].

From a policy perspective, the economic burden of foodborne disease provides a compelling rationale for investment in microbial safety systems. Van Wagenberg *et al*. (2023) [55] found that in Ethiopia and Burkina Faso, losses due to Salmonella, Campylobacter, and enterotoxigenic E. coli amounted to hundreds of millions of international dollars annually—representing substantial

proportions of national income. Proactive monitoring and hygiene improvement programs thus offer strong returns on investment by reducing healthcare costs and preserving workforce productivity.

Finally, coordinated public health frameworks are necessary to unify these strategies. Elbehiry (2023) [18] argues for integrated approaches combining laboratory diagnostics, epidemiological surveillance, outbreak response, and risk communication. Such frameworks can bridge gaps between emerging technology adoption, field-level training, and regulatory enforcement, ensuring that improvements in microbiological safety are consistent and scalable.

### 2.8 Climate and Environmental Influences on Microbiological Risks

The influence of climate and environmental dynamics on microbiological contamination of ready-to-eat (RTE) foods is profound and multifactorial, with implications that cross geographical and socio-economic boundaries. Rising ambient temperatures, altered precipitation patterns, and extreme weather events collectively reshape the ecology of foodborne pathogens, modify their proliferation dynamics, and exacerbate contamination risks along complex food supply chains—from production to retail.

Multiple studies have demonstrated that ambient temperature and humidity are critical determinants in the epidemiology of foodborne diseases. Chua *et al*. (2022) [15], in a systematic review and meta-analysis, showed that higher temperatures significantly increase the incidence and transmission of enteric pathogens such as Salmonella, Campylobacter, and Listeria. The analysis indicates that warmer climates create favourable conditions for pathogen survival and proliferation in both raw ingredients and processed ready-to-eat (RTE) foods, thereby heightening risks across the food chain (Chua *et al*., 2022) [15]. Similarly, Kos *et al*. (2023) [25] emphasise that climate change, particularly rising temperatures and fluctuating precipitation patterns, exacerbates mycotoxin contamination in grains and cereals. Increased fungal activity under humid conditions elevates the risk that ready-to-eat (RTE) products derived from these commodities may simultaneously harbour chemical and microbiological hazards, thereby compounding food safety challenges (Kos *et al*., 2023) [25].

Moreover, the relationship between flooding, surface water contamination, and microbial risk is well established. Bell *et al*. (2021) [8] demonstrate that heavy rainfall and flooding can facilitate the persistence and spread of pathogens such as Vibrio, Escherichia coli, and Salmonella in surface waters and agricultural fields. These contaminated water sources subsequently compromise irrigation and crop surfaces, elevating the risk of contamination in ready-to-eat (RTE) foods even before handling or processing occurs (Bell *et al*., 2021) [8].

Within African contexts, Raimi, Vivien, and Oluwatoyin (2021) [41] describe how climate change, particularly flooding events in Nigeria, exacerbates the spread of pathogenic organisms such as Vibrio cholerae into community water systems and food environments. This process not only heightens contamination risks in water-dependent ready-to-eat (RTE) foods such as seafood and salads but also increases microbial burdens across broader food chains that sustain urban populations (Raimi, Vivien & Oluwatoyin, 2021) [41]. In East Africa, Travis *et al*. (2014) [51] employ a One Health framework to highlight the intricate links between livestock exposure, environmental contamination influenced by seasonal variability, and the emergence of foodborne risks in ready-to-eat (RTE) animal-derived products. Their analysis shows that wetter seasons often heighten pathogen prevalence in cattle, which in turn increases the likelihood of contamination in RTE foods such as dairy, cheese, and meat products, thereby amplifying public health risks in urban populations (Travis *et al*., 2014) [51].

Such climatic challenges also interact with infrastructure limitations and consumer behaviours. Manios (2012) [30] highlights that elevated ambient temperatures accelerate spoilage processes in perishable ready-to-eat (RTE) foods such as meats, salads, and seafood. In contexts where cold chain systems are inadequate—common in low-resource urban settings—these conditions rapidly create environments favourable for microbial growth, turning RTE products into vectors of bacterial proliferation within hours rather than days (Manios, 2012) [30].

Integrating these insights reveals several critical mechanisms by which climate and environment exacerbate microbiological risk in RTE foods:

- Temperature and humidity elevation foster microbial growth rates rather than suppress them, shortening safe consumption windows while increasing pathogen loads in food items.
- Flooding and heavy rainfall promote environmental contamination—carrying pathogens into growing regions and irrigation water, which then directly impacts microbial quality of raw ingredients destined for RTE use.
- Inadequate cold chains and infrastructure in urban markets make spoilage and pathogen proliferation more likely, especially under warming climate conditions.
- Interactions between environmental vectors and food systems—especially within ecosystems involving livestock—heighten contamination potential via direct transfer of pathogens into RTE animal-based products.

Given this evidence, RTE food safety frameworks must adapt to climate volatility. Monitoring systems must incorporate temperature and moisture fluctuations into predictive risk models, routine sampling should be intensified during extreme weather periods, and infrastructure resilience—such as portable cold storage—should be prioritized within urban markets. Equally, integrating environmental pathogen surveillance into food safety systems, leveraging One Health insights, becomes imperative to anticipate and mitigate contamination in increasingly variable climates.

### 2.9 Community Engagement and Public Awareness in Food Safety

In urban centers across low- and middle-income countries (LMICs), ready-to-eat (RTE) foods are a vital component of daily diets, yet often emerge from informal market structures where regulatory oversight is limited. Sustainable improvement of microbiological safety, therefore, depends on robust community engagement and public awareness—movements grounded in trust, cultural resonance, and local ownership.

In Burkina Faso and similar contexts, the effectiveness of communication strategies in shaping consumer food safety behaviours has been evident. Schiro *et al*. (2020) [45] argue that culturally resonant media campaigns, including the use

of television, radio, social media, and other digital platforms, have strong potential to inform consumers, enhance food safety knowledge, and narrow the gap between intention and practice in purchasing decisions. Such interventions demonstrate how engaging communication strategies can shift consumer behaviour and, in turn, exert pressure on vendors to adopt safer practices, reinforcing the role of media-driven initiatives in improving ready-to-eat (RTE) food safety (Schiro *et al*., 2020) [45].

Parallel initiatives in Nigeria further emphasise the significance of local action in strengthening food safety practices. James *et al*. (2020) [23] note that targeted campaigns and educational outreach programmes directed at street food vendors are critical in bridging the gap between technical knowledge and practical application. By promoting sanitation infrastructure, protective behaviours, and collaborative engagement, such interventions reinforce the principle that food safety is a shared responsibility, particularly within informal markets such as those for seafood and other ready-to-eat foods in Lagos (James *et al*., 2020) [23].

Efforts to strengthen food safety and nutrition in Northern Nigeria highlight the importance of community-based interventions. Benson *et al*. (2017) [10], in their study of Kebbi and Bauchi States, observed that local initiatives aimed at improving dietary practices and food handling can play a crucial role in addressing both health and nutrition challenges. Their findings emphasise that visible cues, community engagement, and education not only enhance consumer awareness but also encourage vendors to adopt safer practices, ultimately fostering healthier food environments in contexts marked by high vulnerability (Benson *et al*., 2017) [10].

In Ghana, food safety challenges and interventions highlight the importance of community-level engagement. Christiana Cudjoe *et al*. (2022) [14] emphasise that collaboration between regulators, vendors, and consumers is crucial to improving hygiene practices across production, preparation, and consumption stages. Their work notes that limited access to clean water and sanitation infrastructure remains a significant barrier in traditional markets, but when educational outreach is combined with infrastructural improvements, community norms around food safety can be reshaped, strengthening public health outcomes in both Ghana and Nigeria (Christiana Cudjoe *et al*., 2022) [14].

These interventions align with broader findings in African urban markets, where perceptions of food safety are often shaped more by visible or heuristic cues than by awareness of microbiological risks. Nordhagen *et al*. (2022) observed that both consumers and vendors in Nigeria frequently equated food safety with attributes such as visual cleanliness, absence of flies, and overall freshness, while undervaluing the significance of microbial contamination. Addressing this gap requires participatory education and community engagement initiatives aimed at recalibrating perceptions of risk and aligning everyday practices with established public health priorities (Nordhagen *et al*., 2022).

Fundamentally, community engagement transforms food safety from a regulatory abstraction into a shared social ethic. Improving food safety culture—such as in Nigeria—requires not only technical messaging but embedding safety as a communal norm shaped by trust and mutual responsibility. Onyeaka (2021) [38] reflected that, while Nigeria faces systemic deficiencies, building a durable food safety culture depends on shifting beliefs and everyday practices in both vendors and consumers, rather than solely relying on top-down regulation.

## 3. Conclusion

This study set out to examine the microbiological quality of ready-to-eat (RTE) foods sold in urban markets from a public health perspective, with the overarching aim of identifying key contamination pathways, assessing associated risks, and outlining practical strategies for improving safety. Through a systematic exploration of the conceptual framework, sectoral context, contamination sources, microbial hazards, public health consequences, and feasible interventions, the objectives have been comprehensively addressed.

The findings reveal that RTE foods—whether from formal retail outlets or informal street vendors—are highly susceptible to microbial contamination across multiple stages of the supply chain. Contamination originates both at source and during processing, is exacerbated during distribution and retail, and is significantly influenced by vendor practices, environmental hygiene, and infrastructural constraints. Common microbial hazards include Escherichia coli, Salmonella spp., Listeria monocytogenes, Staphylococcus aureus, and mycotoxin-producing fungi, many of which present acute illness risks and chronic health impacts, including antimicrobial resistance development and carcinogenic exposure.

The study further underscores the substantial public health and socio-economic burden arising from poor microbiological quality—ranging from disease outbreaks and healthcare costs to productivity losses and erosion of consumer trust. Climatic and environmental factors, such as temperature fluctuations, humidity, and flooding, were identified as critical amplifiers of microbial risks, particularly in contexts where cold chain infrastructure is inadequate. Equally, the role of community engagement and public awareness emerged as pivotal in fostering a food safety culture and empowering consumers to make informed choices.

In conclusion, ensuring the safety of RTE foods in urban markets requires an integrated approach. This must combine: robust monitoring systems incorporating rapid detection technologies; vendor training and capacity building; environmental and infrastructural improvements; climate-resilient safety frameworks; and community-driven awareness initiatives. The recommendations arising from this study advocate for stronger regulatory oversight aligned with practical support for vendors, investment in affordable safety technologies, and sustained multi-stakeholder collaboration—bridging public health authorities, food businesses, academia, and consumers.

Ultimately, the insights from this study reinforce that safeguarding the microbiological quality of RTE foods is not merely a technical challenge but a shared societal responsibility, essential for protecting public health, ensuring consumer confidence, and sustaining urban food security.

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