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Ready-to-Eat (RTE) but Not Ready-to-Trust: A Review on Microbial Contamination, Antimicrobial Resistance and Public Health Risks in RTE Foods

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Abstract: *Ready-to-eat (RTE) foods are popular because they can be consumed immediately with little or no preparation. However, the lack of important steps, such as final heat treatment, makes these foods highly susceptible to microbial contamination. The increase in foodborne diseases, caused by such contamination, is a serious public health concern globally. RTE foods can serve as potential carriers for transmitting pathogenic bacteria and antimicrobial-resistant microorganisms to consumers. This review compiles and analyzes research articles published in recent years on microbial contamination and antimicrobial resistance in ready-to-eat foods. Several studies are evaluated to summarize the prevalence of pathogens, sources of contamination, and associated public health risks. Research has reported the presence of various pathogenic bacteria in RTE foods, including Staphylococcus aureus, Escherichia coli, Salmonella spp., Shigella spp., Klebsiella spp., and Bacillus cereus. Many of these pathogens also exhibit antimicrobial resistance, complicating the treatment of foodborne infections. Contributing factors to contamination include poor hygiene practices, improper food handling, and inadequate storage conditions. The issues of microbial contamination and antimicrobial resistance in ready-to-eat foods pose significant threats to food safety and public health. Strengthening food safety regulations, improving hygiene practices, and implementing effective monitoring systems are essential to reducing contamination and ensuring consumer safety.*

Keywords: Ready-to-eat foods, microbial contamination, foodborne pathogens, antimicrobial resistance, food safety, public health.

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1. Introduction

C Ready-to-eat (RTE) foods are becoming increasingly popular in today's fast-paced lifestyle because they require no cooking or additional preparation, making them a time-efficient choice [1] (Figure 1). The range of RTE foods available in the market includes fruits and fruit products, meats and their derivatives, eggs, and more [2]. These foods are defined as "any food item that is typically consumed in its raw state or any processed food that is expected to be eaten without further cooking." RTE foods may be packaged or unpackaged, produced using traditional methods or industrial processes, and are intended for immediate or later consumption [2].

Figure 1: Photographs showing various Ready to Eat food items

RTE foods are particularly popular among urban populations, serving as convenient meal options for individuals in time-sensitive situations while helping them meet their nutritional needs with minimal effort. However, despite their significant benefits, such as time savings, dietary variety, and increased access to nutrition, RTE foods can also pose risks of microbial contamination at various stages. Since these foods are often consumed without a final cooking step, harmful microorganisms may remain viable, posing potential health risks to consumers.

Microorganisms are ubiquitous and can contaminate both cooked and uncooked RTE foods, compromising their quality. The presence of these microorganisms can negatively affect the nutritional value of the food, rendering it unsafe for human consumption. According to the World Health Organization (WHO) and various recent studies, food poisoning remains a serious public health concern. Therefore, evaluating the microbial quality of ready-to-eat foods is crucial for ensuring consumer safety. There is an urgent need to collect data on the microbial quality of both cooked and uncooked RTE foods to better understand their safety, identify potential hazards, and address knowledge gaps for future research [3 & 4].

Some studies have looked into microbial contamination in ready-to-eat (RTE) foods, but there is not enough region-specific data. We urgently need more research to understand contamination, resistance patterns, and how food handling practices affect public health risks. This review paper aims to provide a clear

overview of RTE food contamination in India and around the world.

The main aim of this review paper is to gather and summarize current information on the microbiological quality, dangers from pathogens, and compliance with regulations for RTE foods. By comparing the USD 447.62 billion global industry with India's fast-growing market (28.8% CAGR), this review highlights public health risks linked to changing lifestyles. It assesses bacterial loads, how bacteria spread, and profiles of antimicrobial resistance to help improve vendor handling practices and shape future food safety policies.

2. Status of RTE Food Market: Analysis of the Global and Indian RTE Food Markets

Currently, many working individuals around the world rely on RTE foods, often referred to as convenience foods. The "no-time" culture is a significant factor driving this dependency among working populations.

The market overview illustrates a significant disparity in sheer scale alongside a compelling growth contrast between the global and Indian RTE food sectors. Evaluated for the year 2026, the global RTE market has reached an authoritative valuation of USD 447.62 billion, driven by established consumer behaviors in high-density markets like Europe and North America [5]. In these mature economies, hectic lifestyle patterns, rapid urbanization, and long-standing cold chain logistics networks maintain steady consumer reliance on pre-packaged, ready-to-heat commodities.

In comparison, the Indian RTE market is valued at a modest USD 2.97 billion [6]. This disparity ranks India outside of the top ten global revenue contributors. This positioning is largely a reflection of long-standing cultural differences, as Indian food consumption patterns historically lean heavily toward fresh, scratch-cooked meals prepared daily at home. Furthermore, the regional industry continues to navigate infrastructure barriers, particularly in the deployment of seamless, country-wide cold-chain distribution networks across secondary and tertiary cities.However, evaluating the landscape strictly by raw market capacity obscures the significant structural shift occurring within the subcontinent. Driven by an expanding middle class, a rising population of working young professionals, and a rapid shift toward nuclear household setups, India's RTE sector is expanding at a Compound Annual Growth Rate (CAGR) of 28.8% [6]. This trajectory indicates that while the absolute market size in India remains modest on a global scale, its rapid consumer adoption rates make it one of the most dynamic areas for foreign and domestic agro-processing investment.

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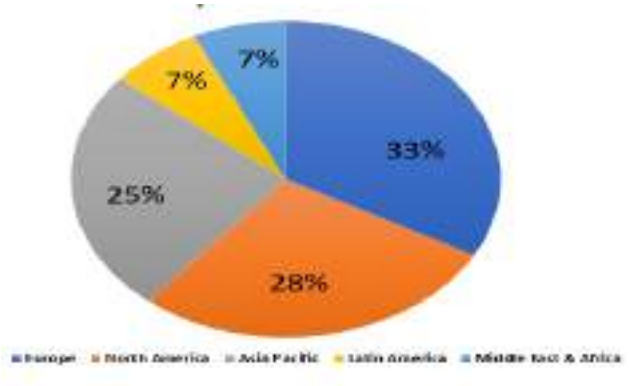

Figure 2: Representing the Global food market of Ready to Eat food items

A pie chart illustrates the distribution of the global RTE food market across different regions. It highlights the relative market share held by each region, reflecting consumption, production, and demand for RTE foods globally (Figure 2). According to this chart, Europe holds the largest share at 33%, indicating a high demand for convenience foods due to busy lifestyles, urbanization, and a strong retail infrastructure. North America follows with 28%, driven by similar factors such as fast-paced living and high disposable income, alongside a well-established food processing industry.

2.1 Status in India

India, with its large population and status as a developing nation, faces significant challenges in ensuring nutritional security. The street food industry plays a crucial role in meeting the food needs of urban residents across many cities and towns. This industry provides millions of people with a wide variety of affordable and accessible food options daily. However, the heavy reliance on street food increases the pressure on this sector to maintain health standards and deliver safe products to consumers. Unfortunately, the industry sometimes falls short, resulting in improperly prepared food that can be contaminated with harmful microorganisms, leading to foodborne illnesses.

3. Microbial Contamination in Ready-to-Eat Foods

Microbial contamination in RTE foods is a significant concern because these foods are consumed without further cooking or processing. This means that microbes can easily survive under favourable conditions and are difficult to eliminate at any stage. The presence of pathogenic and indicator microorganisms can compromise food safety and public health. Since RTE foods are consumed directly or shortly after preparation, any microorganisms present can survive and potentially cause infections.

Contamination can occur at multiple stages, including production, processing, handling, storage, and distribution. Key ingredients, particularly fresh vegetables used in RTE foods like salads, are especially vulnerable to contamination as they are often exposed to soil, water, and environmental microorganisms. A study by Kaneko et al. [7]

highlights the presence of various pathogens, including, *Bacillus cereus*, *Staphylococcus aureus*, and *Listeria species*, in RTE foods, indicating widespread microbial contamination. The study also revealed that bacterial loads can increase during storage, especially under improper temperature conditions, thereby increasing the risk to consumers. These findings emphasize that ready-to-eat foods can serve as vehicles for transmitting foodborne pathogens and underscore the importance of maintaining proper hygiene and storage conditions to ensure food safety [7]. Table 1 representing list of pathogens that are causing contamination in RTE food items.

Table 1 List of pathogens causing contamination in Ready to Eat food items

Microorganism	Name of Disease	Key Symptoms	Incubation Period	Infective Dose	Specific RTE Food Matrix Involved	References
Listeria monocytogenes	Listeriosis	Fever, muscle aches, meningitis, miscarriages	9–48 hours	1,000 cells	Refrigerated meals, deli meats, soft cheeses, unpasteurized dairy	[8]
Staphylococcus aureus	Staphylococcal food poisoning	Acute vomiting, nausea, severe stomach cramps	30 min to 6 hours	100,000 cells	Handled foods requiring no final cooking (sandwiches, sliced meats, pastries)	[9]
***Salmonella* spp.**	Salmonellosis	Acute diarrhea, fever, vomiting, stomach cramps	12–72 hours	100,000 cells	Pre-packaged salads, sprouts, fresh fruits, cross-contaminated meats	[10]
Norovirus	Viral gastroenteritis	Profuse vomiting, watery diarrhea, abdominal cramps	1–2 days	Low	Salads, frosting, baked goods, cold sandwiches handled by infected staff	[11]
Bacillus cereus	Gastrointestinal illness	Diarrhea, abdominal cramps, nausea,	1–15 hours	1,000,000 cells	Pre-cooked rice dishes, pasta salads, ambient-	[8]

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		vomiting			stored savory sauces	
Pathogenic *E. coli* O157:H7	Hemorrhagic colitis	Severe stomach cramps, bloody diarrhea, potential kidney damage	3–4 days	10 cells	Unpasteurized juices, pre-washed raw produce, ready-to-eat salads	[9]

4. Major Pathogens in Ready-to-Eat (RTE) Foods

a) ***Bacterial Pathogens***: Among the various microbial contaminants, bacterial pathogens are the most commonly reported in RTE foods. These include *Escherichia coli*, *Salmonella* spp., *Listeria monocytogenes*, *Staphylococcus aureus*, and *Bacillus cereus*. Major bacteria such as *E. coli* can cause symptoms including diarrhea, abdominal cramps, and hemolytic uremic syndrome, while *Salmonella* spp. is responsible for salmonellosis, which leads to fever, diarrhea, and vomiting. *Listeria monocytogenes* is particularly dangerous because it can grow at low temperatures and may lead to listeriosis, which poses a serious risk to pregnant women, newborns, and immunocompromised individuals. *Staphylococcus aureus*produces heat-stable enterotoxins that can cause food poisoning, and*Bacillus cereus* is known for causing both emetic and diarrheal syndromes through toxin production.

b) ***Fungal Food Pathogens:***In addition to these major pathogens, other bacterial species such as *Klebsiella* spp., *Enterobacter* spp., *Pseudomonas* spp., *Proteus* spp., and *Micrococcus* species have also been detected in RTE foods. While these organisms may not always cause disease, they can act as opportunistic pathogens and serve as indicators of poor hygiene and contamination. Furthermore, fungi such as *Aspergillus* and *Penicillium* may also contaminate food, producing mycotoxins that pose serious health risks, including carcinogenic effects.

5. Sources of Contamination

Pathogens can enter RTE foods through various pathways, including contaminated raw materials, improper food handling, unhygienic preparation environments, contaminated water, and inadequate storage conditions. Cross-contamination from food handlers, equipment, and surfaces significantly contributes to the spread of pathogens. Additionally, inadequate refrigeration and prolonged storage conditions

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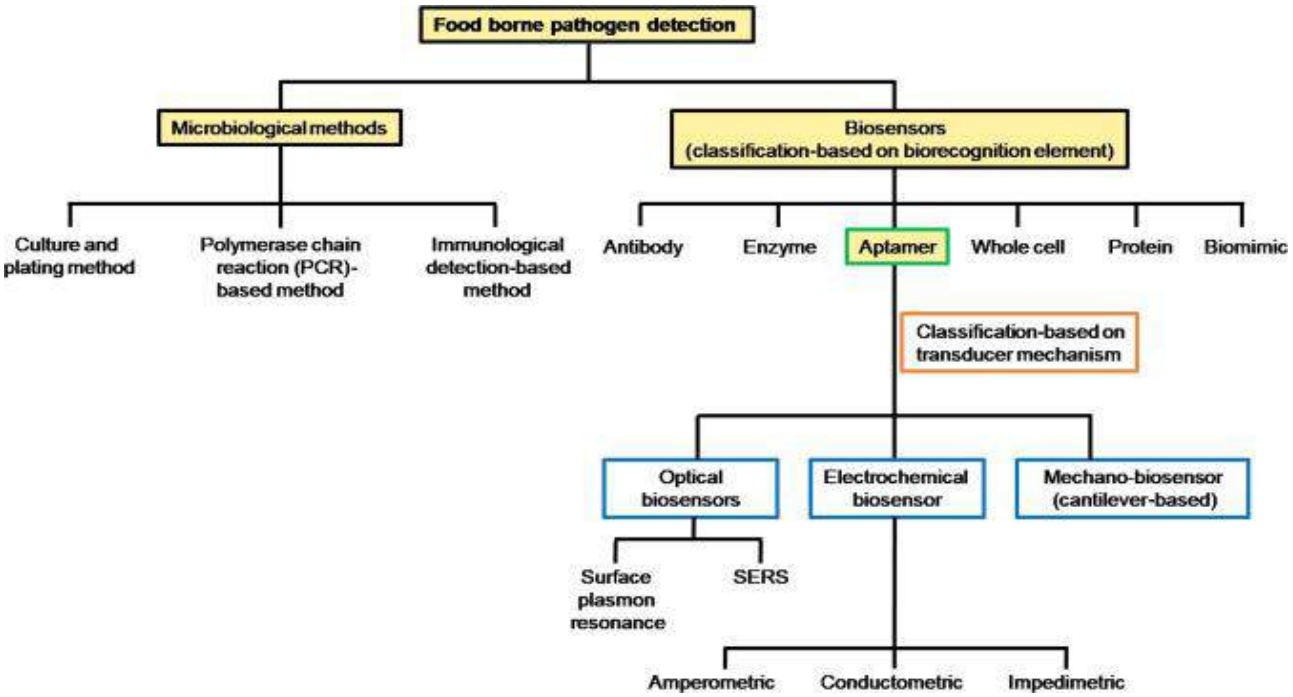
promote microbial growth, thereby increasing the risk of infection.

6. Detection Methods of Food Pathogens



The total viable cell count of fruits and vegetables can be determined using direct microscopic techniques. Stains applied in these methods include nonspecific stains (such as acridine orange and fluorescein isothiocyanate (FITC) and specific stains combined with fluorescent antibodies or oligonucleotide probes designed for pathogens like *E. coli* O157:H7, *Salmonella*, and *Listeria*, as well as for total bacterial counts.

Using the direct epifluorescence filter technique requires several preparation steps: sample filtration through a polycarbonate membrane, collection of bacterial cells from the filter, and staining of the cells with fluorochrome. This technique enables bacterial cell detection, with a detection limit of 1,000 cellsmL^{-1}.

Advancements in biotechnology have led to the development of rapid detection methods that reduce analysis time while providing high sensitivity and specificity in identifying pathogens. One widely used method is Polymerase Chain Reaction (PCR), known for its rapid, sensitive, and specific detection of foodborne pathogens [8].

For bacterial growth and sample enrichment, the following media are commonly used:

- Listeria Enrichment Broth Base, supplemented with Listeria Selective Enrichment Supplement (LEB)
- Fraser Broth Base, supplemented with Fraser Selective Supplement (FB)
- Listeria Selective Agar Base (Oxford), supplemented with Listeria Selective Supplement (Oxford)

These media are reconstituted and supplemented according to manufacturer instructions.

7. Public Health Impact of Microbial Contamination in Ready-to-Eat Foods

The global presence of foodborne pathogens in ready-to-eat (RTE) foods poses significant health risks, primarily because these foods are widely consumed. Inadequate hygiene practices among vendors increase the risk of microbial contamination. RTE foods are particularly popular among school-aged children and the working class in urban areas, significantly impacting their dietary intake. Individuals adopting an urban lifestyle often seek shortcuts in meal preparation and become highly dependent on these RTE foods to meet their nutritional goals. For instance, opting for a cup of frozen yogurt or Greek yogurt instead of a complete protein meal reflects their trust in and reliance on these products. Not only do people consume these products daily, but they also stock them in their refrigerators for convenience. Such practices can severely affect health, leading to various diseases and infections caused by pathogens. Foodborne illnesses such as diarrhea, vomiting, fever, stomach cramps, and more severe diseases like *Listeriosis*, *Salmonellosis*, Viral Gastroenteritis, and Botulism can arise from consuming contaminated RTE foods. Therefore, ensuring food safety is critical, yet it remains a global challenge affecting both developed and developing nations, significantly impacting public health and economic progress [13].Moreover, the consumption of microbiologically contaminated RTE foods contributes substantially to the global burden of foodborne diseases. The World Health Organization (WHO) reports that these diseases affect approximately 600 million people and cause nearly 420,000 deaths worldwide each year. Such figures highlight the serious impact of these pathogens on public health when consumed in large quantities [14]. Foodborne infections are a major cause of morbidity and mortality, especially in developing countries where inadequate food safety practices, poor sanitation, and lack of awareness heighten the risk of contamination [15]. Vulnerable populations, such as children, the elderly, pregnant women, and immunocompromised individuals, are at higher risk of severe complications, including hospitalization and death.

Overall, while ready-to-eat foods are popular, they cannot be completely trusted as they serve as significant vehicles for the transmission of pathogenic microbes, which can

directly enter the human body [16]. Furthermore, foodborne diseases impose a considerable burden on healthcare systems, driving up medical costs, hospital admissions, and the demand for healthcare services [14]. Besides the health impact, these illnesses can lead to substantial economic losses in the long run due to decreased productivity and increased healthcare expenditures. The emergence of antimicrobial-resistant foodborne pathogens has become a growing public health concern, complicating treatment and increasing the risk of severe infections [17]. As such, ensuring the microbiological safety of ready-to-eat foods through proper hygiene practices, safe food handling, adequate storage, and effective food safety regulations is essential to prevent foodborne diseases and protect public health globally.

8. Emergence of Antimicrobial Resistance (AMR) inRTE Foodborne Pathogens

Antimicrobial resistance (AMR) occurs when pathogens, including viruses, bacteria, fungi, and parasites, do not respond to antimicrobial treatments in humans and animals, allowing these microorganisms to survive within their hosts. Globally, AMR has emerged as a chronic public health problem, with a forecast of 10 million deaths per year by 2050. The primary cause of this crisis is the overuse and misuse of antimicrobials, particularly the inappropriate use of antibiotics, which is significantly contributing to the global burden of AMR [18].

To combat infectious diseases, a range of chemicals known as antimicrobial agents have been developed. These agents are effective in limiting, preventing, or eliminating microbial growth. Most of these antimicrobials are derived from natural products that various organisms originally used as a defense against microbial attacks. These natural products have been isolated and characterized, with many modified by humans to enhance their antimicrobial activity. While many antimicrobial agents target specific types of pathogens, others may affect a broad range of microbes. These agents include antiseptics, antibiotics, antifungals, and anti-helminthics, among others [19].

Many foodborne pathogens that exhibit resistance to commonly used antibiotics have been isolated from RTE foods. Pathogens such as *Escherichia coli*, *Salmonella* spp., and *Staphylococcus* spp. are commonly found in various RTE food items, including meats, poultry products, salads, vegetable dishes, and sandwiches. These pathogens significantly contribute to foodborne infections, and their increasing resistance to antimicrobial agents poses a serious challenge to food safety and public health. Antimicrobial-resistant bacteria can transfer to humans through the food chain. Consuming contaminated ready-to-eat food allows resistant microorganisms to enter the

gastrointestinal tract and facilitates the transfer of resistance genes among bacterial populations. The presence of antimicrobial-resistant pathogens in RTE foods presents a significant public health concern, as infections caused by these resistant pathogens are difficult to treat due to the reduced effectiveness of antibiotics. The rising prevalence of resistant pathogens in RTE foods contributes to the global increase in multidrug-resistant infections. To limit the spread of antimicrobial-resistant bacteria in ready-to-eat foods, effective control strategies are required. These strategies include improving hygiene practices among food vendors, implementing food safety regulations, and strengthening surveillance systems to monitor antimicrobial resistance in foodborne pathogens [20].

9. Factors responsible for contamination in RTE

Several factors contribute to this contamination, including traditional processing methods, inadequate holding temperatures, and poor personal hygiene among food handlers. As noted in various studies, consumers who frequently rely on street food prioritize convenience often overlooking crucial aspects like safety, quality, and hygiene. Reports of foodborne illness linked to RTE foods have emerged in India and other regions [21,22, 23, 24, 25]. Such illnesses are often associated with diarrheal diseases, attributable to improper use of additives, the presence of pathogenic bacteria, environmental contaminants, and neglect of good manufacturing and hygiene practices [25].

10. Raw Material Hazards and Regulatory Compliance for RTE Products

To ensure the safety of RTE foods, it is imperative to maintain quality control of raw materials. Given the diverse sources of these materials and the complexity of processing technologies, RTE products face multiple safety risks throughout the farm-to-table supply chain. Studies indicate that raw materials may be contaminated with pesticide residues, veterinary drug residues, heavy metals, microorganisms, and mycotoxins during cultivation, storage, and transportation.

Excessive microbial content has been observed in certain food samples, suggesting significant microbial contamination in ready-to-eat meat products. In the production of ready-to-eat salads, harmful microorganisms like *E. coli*, *Salmonella*, and *Staphylococcus aureus* can cause spoilage. The European Regulation (EC) No. 2073/2005 outlines microbiological standardsthe permissible limits for harmful microorganismsthat must be enforced in specific food items. It mandates that food business operators adhere to proper hygiene practices to ensure food safety.

For L. monocytogenes, this regulation details protocols for RTE food products:

1. In RTE products intended for infants and special medical purposes, L. monocytogenes must not be detected in 10 × 25 g samples.

2. For RTE products not aimed at infants or special medical purposes, different microbiological criteria apply, depending on the food's potential to support L. monocytogenes growth.

3. For RTE foods that can support the growth of L. monocytogenes, levels must remain below 100 CFU/g throughout the product's shelf life (n = 5; c = 0).

In 2019, the Food Net identified 25,866 incidents of foodborne illness, leading to 6,164 hospitalizations and 122 deaths. Microorganisms such as *Salmonella*, *Listeria*, *Escherichia coli*, and Campylobacter are the primary agents of gastrointestinal foodborne illnesses in the United States. To reduce these illnesses, ongoing development of effective intervention strategies is necessary. While antimicrobials have been used in food for centuries, consumers increasingly demand alternatives perceived as "natural." In recent years, there has been a growing popularity for RTE processed meat products that do not contain synthetic chemicals. The food industry continuously seeks improved technologies for producing RTE meat products, responding to consumer demands for convenient, flavorful, and wholesome options [26].

11. Conclusion

In conclusion, the prevalence of bacterial contamination in ready-to-eat foods significantly contributes to infections and food poisoning. The rise in foodborne diseases highlights issues of food hygiene, often due to a lack of awareness and disregard for health principles. Fast food consumption poses serious risks requiring further investigation. To mitigate these risks, personnel training in fast-food preparation is essential, with an emphasis on adherence to health regulations. Careful oversight in preparation, transportation, storage, and service is critical to prevent microbial contamination. The emergence of antimicrobial-resistant foodborne pathogens adds to public health concerns, as these bacteria complicate treatment options. Continuous monitoring and effective implementation of food safety regulations, along with good manufacturing and hygiene practices, are vital for ensuring the safety of ready-to-eat foods. Regulatory authorities, such as the World Health Organisation, emphasise the need for stringent food safety standards and increased awareness among food vendors and consumers. Future research should focus on improving detection methods, enhancing resistance surveillance, and developing strategies to control contamination, ultimately promoting food safety and safeguarding public health.

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