Chapter

Pathogens Transmitted through Contaminated Rice

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Abstract

Rice can be a source of food poisoning because it can be contaminated with dangerous pathogens. Pathogens that often transmitted through rice are *Bacillus cereus* and *Staphylococcus aureus*. This chapter aims to explain the dangers of pathogens transmitted through contaminated rice, modes of transmission, contamination cases, and precautions. The method used in writing is to review articles. It is known that pathogens transmitted through contaminated rice can cause food poisoning, which occurs due to consuming rice containing pathogenic bacteria. Several cases of contamination of *Bacillus cereus* and *Staphylococcus aureus* in rice occurred in Indonesia, Pakistan, India, Malaysia, Belgium, America, Australia, Korea, Iran, China, and Nigeria. In general, prevention is by proper handling of raw materials, controlling the temperature of cooking and storing rice, and personal hygiene of food handlers.

Keywords: rice, pathogens transmitted, food poisoning, *Bacillus cereus*, *Staphylococcus aureus*

1. Introduction

Most of the world's population, especially Asia, use rice as the primary source of carbohydrates in their daily menu. Rice, as a staple food, is usually served with side dishes to complement the taste and also complement one's nutritional needs. Rice can process with other food ingredients into new dishes, such as fried rice, yellow rice, or uduk rice.

Rice can be a source of food poisoning because it contaminated with dangerous pathogens. In general, food poisoning can cause by contaminant bacteria such as *Bacillus cereus*, *Staphylococcus aureus*, *Salmonella* group (except *Salmonella typhi*), *Shigella, Vibrio, Escherichia coli, Campylobacter, Yersinia enterocolitis, Clostridium* [1]. Rice-based food poisoning more often caused by *Bacillus cereus* and *Staphylococcus aureus* based on several cases in the world [2–15]. Besides, *Bacillus cereus* and *Staphylococcus aureus* are significant sources of microbiological harm from cereal grains and related products [16].

Bacillus cereus can found in soil, plants, and the intestinal tract of insects and mammals. In poor environmental conditions, bacteria can turn into spore forms. *Bacillus cereus* in spore form can found hiding in raw rice. The bacteria move from the soil to the paddy fields, their spores persist for years, even surviving during cooking due to their resistance to extreme temperatures. However, if rice left at room temperature, in warm and humid conditions, the spores can turn into bacteria and produce toxins that can cause vomiting and diarrhea [17].

Staphylococcus aureus is naturally present in the human body, so these bacteria are one of the essential agents causing food poisoning that often occurs in society. The most significant cause of *Staphylococcus aureus* entry into the food chain (which then causes staphylococcal poisoning) is the low sanitation of workers handling food [18].

According to the Food Standards Agency (FSA), there are nearly 900,000 food poisoning cases each year. The lifestyle that has changed in recent years has resulted in an increasing dependence on ready-to-eat food, eating out more than cooking, busyness results in having less time to prepare and cook food. This habit is the reason that increases the number of cases of food poisoning [19]. Apart from that, environmental factors also influence the level of contamination. Food prepared under unfavorable conditions and environment implies a higher incidence of food poisoning than others [18]. Food poisoning occurs more frequently in developing countries than in developed countries. This situation is due to differences in the level of sanitation between developed and developing countries [18].

2. Pathogenic *Bacillus cereus* transmitted through rice

2.1 Characteristics and diseases caused by *Bacillus cereus*

Bacillus cereus is a spore-forming bacteria that produces a toxin that causes vomiting or diarrhea. Symptoms are generally mild and short-lived (up to 24 h). *Bacillus cereus* commonly found in the environment (e.g., soil) and various foods. Spores are able to withstand harsh environments, including average cooking temperatures. *Bacillus cereus* is a Gram-positive, motile (flagellated), spore-forming, rod-shaped bacterium belonging to the genus Bacillus. Species in this genus include *Bacillus anthracis, Bacillus cereus, Bacillus mycoides, Bacillus thuringiensis, Bacillus pseudomycoides, and Bacillus weihenstephanensis* [17, 20].

Bacillus cereus is widespread and easy to find in the soil, where it adopts a saprophytic life cycle, germinate, grow, and sporulate in this environment [21]. Spores are more resistant to environmental stress than vegetative cells because of their metabolic dormancy and hard physical properties [22].

Bacillus cereus causes two types of diseases, namely emetic syndrome and diarrhea syndrome. Emetic syndrome causes by emetic toxins produced by bacteria during the growth phase in food, a diarrheal syndrome caused by diarrheal toxins produced during bacterial growth in the small intestine [23].

Bacillus cereus has a mesophilic or psychrotrophic strain. Mesophilic strains grow well at 37°C but do not grow below 10°C, whereas psychrotrophic strains grow well at cold temperatures but grow poorly at 37°C [24]. All *Bacillus cereus* isolates associated with emetic toxin production have found to be mesophilic [25]. *Bacillus cereus* growth is optimal in the presence of oxygen, although it continues to grow under anaerobic conditions. *Bacillus cereus* cells grown in aerobic conditions were less resistant to heat and acid than *Bacillus cereus* cells that grew anaerobically or microaerobically [26]. *Bacillus cereus*' mesophilic strains have shown to have higher acid resistance than psychotropic strains [25].

Spores are more resistant to dry heat than humid heat, with heat resistance usually higher in foods with lower water activity. Spores are also more resistant to radiation than vegetative cells [22]. Nisin is a preservative that used to inhibit germination and spore growth. Antimicrobials that inhibit the growth of *Bacillus cereus* include benzoic, sorbic, and ethylenediaminetetraacetic acids [22].

Symptoms of *Bacillus cereus* disease cause two types of foodborne illness, namely emetic syndrome (vomiting) and diarrhea. Vomiting syndrome is poisoning caused by the ingestion of a cyclic peptide toxin called cereulide that has been pre-formed in food during growth by *Bacillus cereus*. This syndrome has a short incubation period and recovery time. Symptoms of nausea, vomiting, and stomach cramps occur within 1–5 h after ingestion, with recovery usually within 6–24 h [27].

The diarrheal syndrome caused by enterotoxins produced by *Bacillus cereus* in the host body, the incubation period before the onset of the disease is 8–16 h, and infection usually lasts 12–14 h. However, it can continue for several days. Symptoms are generally mild, with stomach cramps, watery diarrhea, and nausea [28]. In a small number of cases, both toxins produced, and vomiting and diarrhea develop [17].

No form of the disease is considered life-threatening for normal healthy individuals, with few fatal cases reported [22]. *Bacillus cereus* has been associated with the non-food-related illness, although this is rare. These bacteria have been found in postoperative and traumatic wounds and can cause opportunistic infections, especially in individuals with immune system disorders, such as septicemia, meningitis, and pneumonia. *Bacillus cereus* has also known to occasionally cause localized eye infections in humans [29].

The pathogenic mechanisms for *Bacillus cereus* emetic disease are well known. Emetic toxins (cereulide) cause vacuole formation in HEp-2 cells in the laboratory [29]. Cereulide in experimental animals caused vomiting, potentially by binding to 5-HT3 receptors in the stomach/small intestine to stimulate the vagus nerve and brain [30]. Cereulide produced by the Non-Ribosomal Peptide Synthetase Complex (NRPS) [31]. All NRPS clusters have characterized [23], resulting in a precise method for detecting cereulide-producing *Bacillus cereus* strains [32]. Emetic toxin production has shown to occur in skim milk in the temperature range of 12–37°C, with more toxins produced at 12 and 15°C than at higher temperatures [33]. Emetic toxins are highly resistant to environmental factors, exhibiting stability from a pH of 2–11 and heating to 100°C for 150 min (pH 8.7–10.6) [22].

Three types of enterotoxins are associated with a form of diarrhea syndrome, namely three components of the enterotoxin Hemolysin BL (HBL), three parts of Non-Hemolytic Enterotoxin (NHE) and one element of cytotoxin K. Enterotoxins are released into the small intestine by the surviving vegetative cells of *Bacillus cereus* [34]. Diarrheal enterotoxins are stable at pH 4–11 and deactivated by heating to 56°C for 5 min [22].

Up to 26% of the vegetative cells of *Bacillus cereus* can survive as they travel through the stomach. Diarrheal enterotoxins are unstable at low pH in the stomach and degraded by digestive enzymes. Any previously formed enterotoxins in food are destroyed during passage through the stomach so that they do not cause disease if ingested [22]. In contrast, *Bacillus cereus* spores can pass unaffected by the gastric barrier. Spores need to be triggered by nutrients and intestinal epithelial cells to initiate germination. In the small intestine, spores germinate, grow and produce enterotoxins [35].

A vital virulence factor required to cause diarrhea symptoms is the ability of vegetative cells and *Bacillus cereus* spores to adhere to the small intestine's epithelial cell walls. Spore and cell adhesion efficiency show to be low, around 1% [35]. Enterotoxins' ability to damage tissue and damage the plasma membrane of small intestinal epithelial cells plays a role in causing diarrhea [27].

2.2 Mode of transmission *Bacillus cereus* food poisoning

The pattern of transmission *Bacillus cereus* food poisoning can be caused by ingesting large numbers of bacterial cells and spores in contaminated food (diarrhea type) or by ingesting food contaminated with pre-formed toxins (emetic type). Transmission of this disease caused by the consumption of contaminated food, improper handling/storage of food, and inadequate cooling of cooked food [36].

Year	Food	Country	Findings	Article title
2009	Brown rice and glutinous rice	Korea	15 (37%) of 83 samples of brown rice, 23 (37%) of 63 samples of glutinous rice	Prevalence, Genetic diversity, and Antibiotic Susceptibility of *Bacillus cereus* Strains Isolated from Rice and Cereals Collected in Korea [2]
2009	Raw rice	Amerika	*Bacillus* species spores found in 94 (52.8%) rice samples with an average concentration of 32.6 CFU/g	Detection of Toxigenic *Bacillus cereus* and *Bacillus thuringiensis* in US Rice [3]
2012	Cooked rice (white rice, fried rice)	Belgia	The concentration of cereulide found in rice dishes is around four ng/g	Prevalence and Levels of *Bacillus cereus* Emetic Toxin in Rice Dishes Randomly Collected from Restaurants and Comparison with the Levels Measured in a Recent Foodborne Outbreak [4]
2012	Cooked and raw rice	Pakistan	All rice samples showed the presence of *Bacillus cereus*, the highest number: 3.34 × 101 CFU/ml	Microbial Assessment of Uncooked and Cooked Rice Samples Available in Local Markets of Lahore [5]
2013	Baby food (made from rice)	Iran	*Bacillus cereus* and its enterotoxigenic genes have found in infant diets in Iran	*Bacillus cereus* in Infant Foods: Prevalence Study and Distribution of Enterotoxigenic Virulence Factors in Isfahan Province, Iran [6]
2018	Local unhulled (coarse) rice	Malaysia	The number of *Bacillus cereus* bacteria in all samples found to be more than 1100 MPN/g	Presence of *Bacillus cereus* from Local Unhusked (Rough) Rice Samples in Sarawak, Malaysia [7]
2019	Cooked rice (yellow rice)	Indonesia	21% of yellow rice contaminated with *Bacillus cereus*	*Staphylococcus aureus* and *Bacillus cereus* in Yellow Rice [8]
2020	Rice/ noodles	China	59 out of 119 rice/noodle samples (50%) were positive for *Bacillus cereus*	A Study on Prevalence and Characterization of *Bacillus cereus* in Ready-to-Eat Foods in China [9]

Table 1.
Cases of Bacillus cereus *contamination in rice (rice-based food).*

2.3 Case contamination and precautions for *Bacillus cereus* in rice

Cases of contamination of *Staphylococcus aureus* on rice, either in the form of raw rice or cooked rice and other processed rice products, are found in several countries. Further explanations can see in **Table 1**.

Precautions for contamination of *Bacillus cereus* in rice:

1. Processing (thoroughly cooked and quickly cooled) is one of the easiest ways to prevent foodborne illness associated with Bacillus spp. [37].

2. Hot foods should store at 140°F/60°C or higher [37].

3. Reheating cooked food should be stored at 165°F/74°C [37].

4. If frozen food is allowed to thaw, it must remain at 41°F/5°C or lower [37].

5. Steaming under pressure, roasting, frying, and grilling foods will destroy the vegetative cells and spores if temperatures within foods are ≥ 145ºF/63ºC [38].

6. Foods that contain emetic toxins need to be heated to 259°F/126°C for more than 90 min—reheating food until steaming is not sufficient to kill emetic toxins [38].

3. Pathogenic *Staphylococcus aureus* transmitted through rice

3.1 Characteristics and diseases caused by *Staphylococcus aureus*

Staphylococcus aureus is one of the bacteria that cause food poisoning. *Staphylococcus aureus* is commonly found in the environment (soil, water, and air) and located on humans' nose and skin. *Staphylococcus aureus* is a spherical, Gram-positive, non-spore bacteria. The genus Staphylococcus divided into 32 species and subspecies. *Staphylococcus aureus* causes food poisoning by producing Staphylococcal Enterotoxin (SE) [39, 40].

Staphylococcus aureus's growth and survival depend on several environmental factors such as temperature, water activity (aw), pH, presence of oxygen, and food composition. These physical growth parameters varied for different strains of *Staphylococcus aureus* [41]. The temperature range for *Staphylococcus aureus* growth is 7–48°C, with an optimum temperature of 37°C. *Staphylococcus aureus* is resistant to freezing and does well in foods stored below −20°C; however, viability is reduced at −10 to 0°C. *Staphylococcus aureus* easily killed during pasteurization or cooking. *Staphylococcus aureus* growth occurs in the pH range 4.0–10.0, with an optimum of 6–7 [41].

Staphylococcus aureus is a facultative anaerobe so it can grow in both aerobic and anaerobic conditions. However, growth occurs at a much slower rate under anaerobic conditions [41]. For non-sporing mesophilic bacteria, *Staphylococcus aureus* has relatively high heat resistance [41]. A highly heat resistant *Staphylococcus aureus* strain (D-value at 60°C > 15 min in broth) has identified from foodborne outbreaks in India [42].

Several chemical preservatives, including sorbate and benzoate, inhibit the growth of *Staphylococcus aureus*. The effectiveness of this preservative increases as the pH decreases. Methyl and propyl parabens are also useful [41, 43].

Symptoms of staphylococcal food poisoning generally have a rapid onset, appearing approximately 3 h after ingestion (range 1–6 h). Common symptoms include nausea, vomiting, stomach cramps, and diarrhea. The individual may not show all the signs associated with the disease. In severe cases, headaches, muscle cramps, and temporary changes in blood pressure and pulse may occur. Recovery is usually between 1 and 3 days [39, 41]. Death is rare (0.03% for the general population) but occasionally reported in children and the elderly (death rate 4.4%) [40]. *Staphylococcus aureus* can cause various health problems not related to food such as skin inflammation (e.g., ulcers and style), mastitis, respiratory tract infections, wound sepsis, and toxic shock syndrome [40, 41].

Staphylococcal food poisoning caused by the ingestion of foods containing pre-formed SE [44], there are several types of SE; enterotoxin A is most commonly associated with staphylococcal food poisoning. Enterotoxins D, E, and H, and to a lesser extent B, G, and I have also associated with staphylococcal food poisoning [45, 46].

SE produced during the exponential phase of *Staphylococcus aureus* growth in a strain-dependent quantity. Typically, the disease-inducing dose of SE occurs when at least 105–108 CFU/g of *Staphylococcus aureus* are present [45, 40]. Most of the genes for SE located in plasmid or prophage elements. Thus, transfer between strains can occur, modifying the ability of *Staphylococcus aureus* strains to cause disease and contributing to pathogen evolution [44, 46].

As the temperature decreases, the SE production rate also decreases. However, SE remained stable under frozen storage. SE is highly resistant to heating and can withstand the processes used to sterilize low-acid canned foods. SE production can occur in the pH range 4.5–9.6, with an optimum of 7–8. SE production can occur in anaerobic and aerobic environments; however, toxin production is optimal under aerobic conditions [41].

3.2 Mode of transmission. *Staphylococcus aureus* food poisoning

Staphylococcal food poisoning occurs when the food consumed contains SE produced by *Staphylococcus aureus*. Food handlers carrying enterotoxin-producing *Staphylococcus aureus* in their nose or hands are considered a significant source of food contamination through direct contact or respiratory secretions [44].

Year	Food	Country	Findings	Article title
2001	Rames rice	Indonesia	The number of *Staphylococcus aureus* in the rice sample: 3.21 Log CFU/g	Study of Microbiological Safety of Snack Food at the FATETA-IPB Canteen, Bogor [10]
2003	Rice at the restaurant	Brazil	Rice containing *Staphylococcus aureus*: 100 CFU/g	An outbreak of staphylococcal food poisoning in the Municipality of Passos, MG, Brazil [11]
2004	Rice cake	Korea	19.3% of rice cakes were contaminated with *Staphylococcus aureus*	Occurrence of Toxigenic *Staphylococcus aureus* in Ready-to-Eat Food in Korea [12]
2010	Uduk rice	Indonesia	The frequency of isolation of coagulase-positive *Staphylococcus aureus* in uduk rice samples was 6.67%, and not all were found in sufficient amounts to form enterotoxins.	Risks of *Staphylococcus aureus* in Traditional Ready-to-Eat Food and Evaluation of Its Presence in uduk Rice [13]
2014	Kerala matta rice	India	Kerala matta rice samples contained coagulase-positive *Staphylococcus aureus*.	Outbreak of Staphylococcal Food Poisoning [14]
2019	Yellow rice	Indonesia	7% of yellow rice contaminated with *Staphylococcus aureus*	*Staphylococcus aureus* and *Bacillus cereus* in yellow rice [8]
2019	Jollof rice	Nigeria	*Staphylococcus aureus* found in jollof rice samples at the campus cafeteria.	Identification and anti-bacterial Testing of *Staphylococcus aureus* Isolated from Jollof Rice sold at selected Cafeterias in Federal University [15]

Table 2.
Cases of Staphylococcus aureus *contamination in rice (rice-based food).*

It estimated that in the US, *Staphylococcus aureus* accounts for 2.6% of foodborne diseases caused by 31 significant pathogens [47]. The incidence of staphylococcal food poisoning is seasonal. Most cases occur in late summer when temperatures are warm, and food is stored incorrectly [40].

Foods associated with the staphylococcal food poisoning outbreak include meat and meat products, poultry and egg products, milk and dairy products, salads, cream sandwich products, and sandwich stuffing. Foods that require extensive handling during preparation and stored above refrigeration temperature (4°C) for a long time after development frequently implicated in staphylococcal food poisoning [39]. Foods high in starch (such as rice) and protein believed to support SE production [41].

3.3 Case contamination and precautions for *Staphylococcus aureus* in rice

Cases of contamination of *Staphylococcus aureus* on rice, either in the form of raw rice or cooked rice and other processed rice products, are found in several countries in the world. Further explanation can see in **Table 2**.

Precautions for contamination of *Staphylococcus aureus* in rice:

1. The permissive temperature for growth and toxin production by *Staphylococcus aureus* is between 6 and 46°C. Thus, the ideal cooking and cooling temperatures should be above 60°C and below 5°C, respectively, is below the recommended temperature [48].

2. Serving food quickly when stored at room temperature, wearing gloves, masks, hairpins during food handling and processing, washing hands frequently, maintaining personal hygiene for food handlers can help prevent *Staphylococcus aureus* contamination [49].

3. Other precautions such as raw material control, proper handling and processing, adequate cleaning, and disinfection of equipment used in food processing and preparation must take [50].

4. Environmental factors that can play an essential role in the proliferation of bacteria and the production of *Staphylococcus aureus* enterotoxins are the storage of rice at room temperature for an extended period between preparation and consumption [14].

4. Conclusions

It knows that pathogens transmitted through contaminated rice can cause food poisoning, which occurs due to consuming rice containing pathogenic bacteria. Several cases of contamination of *Bacillus cereus* and *Staphylococcus aureus* in rice occurred in Indonesia, Pakistan, India, Malaysia, Belgium, America, Australia, Korea, Iran, China, Nigeria. In general, prevention by proper handling of raw materials, controlling the temperature of cooking and storing rice, and personal hygiene of food handlers.

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Conflict of interest

The authors declare no conflict of interest.

Acronyms and abbreviations

HBL	hemolysin BL
NHE	non-hemolytic enterotoxin
SE	staphylococcal enterotoxin

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