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Staphylococcus aureus and Its Association with Foodborne Illnesses

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Abstract

Staphylococcus aureus is one of the most important pathogens that is represented as one of the most critical causes of foodborne illness. The bacteria have ability to contaminate a variety of food items, some of them are meat, milk, poultry, bakery and ready-to-eat food provided in market. A defining feature of its pathogenicity is the ability to produce heat-stable enterotoxins, those remains bio-chemically active even after cooking, pasteurization or different methods used during food processing. Poor hygiene, improper handling during food processing, and non-maintenance of suitable storage temperature are also the reasons of food contamination. Apart from foodborne illness, the emergence and spread of anti-microbial resistant strains, particularly methicillin-resistant *Staphylococcus aureus* (MRSA), have increasingly worsened the public health. This mini review presents association of *Staphylococcus aurus* with foodborne illnesses and its detection in food materials and control measures.

Keywords: *Staphylococcus aureus***,** Antimicrobial- resistance (AMR), Methicillin- resistance *Staphylococcus aureus* (MRSA), Food safety, and Virulence factors

Introduction

Foodborne illnesses remain as important public health challenges, affecting millions of individuals every year. Among all the bacterial organisms responsible for the food poisoning, the *Staphylococcus aureus* is one of major cause for foodborne diseases. The bacteria release some toxins commonly known as *Staphylococcal* enterotoxins. These are type of heat-stable proteins causing symptoms like vomiting, abdominal cramps, diarrhea and nausea on consumption of contaminated food. *Staphylococcus* food poisoning occurs due to pre-formed toxins, not the bacteria itself. *Staphylococcus aureus* is commonly found on skin surface, nasal passages, and in the mouth of healthy human and animals. Food contamination happens frequently because of the carelessness handling of foods during processing and improper storage temperature. The pathogen can survive in many environmental factors, which may include high salt and adversative temperature ranges and thus adaptability to different food environments.

Characteristics of *Staphylococcus aureus*

Morphologically, *Staphylococcus aureus* is non-motile, non-spore-forming coccus and gram-positive bacterium that gives the impression of grape-like clusters under a microscope. Its colonies are characteristically golden- yellow because of carotenoid pigments it produces. The bacteria are facultative anaerobic and catalase-positive. *Staphylococcus aureus* shows best growth at temperatures between 35-37ºC, but it has ability to survive in a range of environmental temperatures and having ability to grow in high salts concentration of processed foods. In presence of mannitol sugar in growth media, it produces yellow colonies due to acid production. Biochemically, *Staphylococcus aureus* is catalase test positive, coagulase test positive, and oxidase test negative.

Spreading and entrance into the food chain

Humans, livestock, poultry, and dairy animals are the natural sources of *Staphylococcus aureus*. Humans are the good source of contamination as the bacteria regularly survive on the skin, nasal passages, and hands. There are many ways for the organism to enter the food chain such as; (i) unsanitized hands and skin of food handlers, (ii) contaminated raw materials (milk and meat from mastitis animals) (iii) improper storage temperature facilitate bacterial growth, (iv) contaminated water, utensils, containers, equipment used during food processing, (v) diseased/ infected animals, (vi) unhygienic slaughtering practices, (vii) environmental sources *etc.*

Virulence factors of *Staphylococcus aureus*

The pathogenicity of *Staphylococcus aureus* is mediated by an array of virulence factors. These components enable bacteria to colonize the host tissues, evade immune system, and cause severe systemic damage through toxin production.

I. ***Staphylococcus* enterotoxins (SEs):** Enterotoxins are key virulence drivers in Staphylococcal food poisoning. Among the major forms (SEA, SEB, SEC, and SEE), SEA is the most prevalent toxin found in food poisoning cases. This type of enterotoxins is highly persistent and resistant to heat processing and proteolytic

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digestive enzymes, making it extremely difficult to eliminate using ordinary cooking processes.

II. **Coagulase:** This enzyme catalyzes the alteration of soluble fibrinogen into insoluble fibrin. The coagulase enzyme creates a protective fibrin defense layer all around the bacterial cells and thus defend *Staphylococcus aureus* from host immune detection and phagocytosis.

III. **Hemolysins:** Hemolysins act by damaging the cellular membranes of erythrocytes and other host tissues. This lytic activity directly induces cytotoxic effects, helping bacterial spread and severe tissues damage.

IV. **Biofilms Formulation:** There are some specific strains of *Staphylococcus aureus* that can form the structure of biofilms. This extracellular matrix allows the bacteria to stick always to the surfaces of food materials, thus greatly increasing their resistance to sanitation, cleaning, and disinfection procedures.

V. **Exoenzymes:** Exoenzyme such as lipases, proteases, and nucleases help the bacteria occupy tissues and survive in the host.

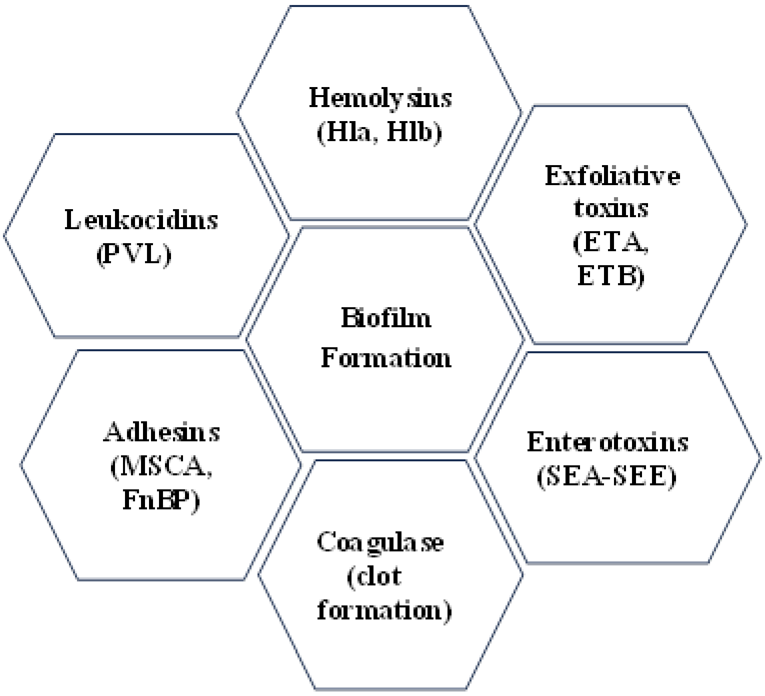

Figure 1: Virulence factor of *S. aureus*

Staphylococcus aureus in foodborne diseases

Staphylococcus aureus is associated to many food poisoning outbreaks occurred globally. Ready-to-eat food items, meat, dairy products are normally involved in most of foodborne illnesses. *Staphylococcus aureus* produces enterotoxins that remain active even after the food is cooked or processed. Some of toxins are heat- resistant and tolerant to acidic

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environment and digestive enzymes of stomach, enabling the organism to cause diseases even when the live bacteria are not present. Symptoms of *Staphylococcus* food poisoning such as vomiting, nausea, stomach cramps, diarrhea *etc*. typically appear 2 to 6 hours after eating contaminated food.

Foodborne outbreaks linked to "*Staphylococcus aureus*" have been reported globally. In developing countries, issues such as poor sanitation, insufficient refrigeration infrastructure, and improper food handling raise the risk of contamination and microbe proliferation.

Parameters	Global Scenario	Indian scenario
Annual foodborne diseases burden	~600 million illnesses and 420,000 death per year from unsafe food globally.	Despite poor hygiene and inadequate surveillance systems, foodborne diseases still remain a major public health problem.
Staphylococcus aureus in uncooked meat.	Prevalence rate globally: 29.2%	Most common detected in poultry, beef, chevon, and street meat products.
MRSA prevalence in food products	Global MRSA prevalence in meat: 3.2%	Increasing occurrence cases of MRSA strains in dairy and meat products have been reported in India.
Prevalence in milk and dairy products	Prevalence of contamination in raw milk: 33.36% globally	High prevalence of contamination in raw milk, panner, khoa, and dairy products sold locally.
Foods that may be contaminated	Meat, poultry, milk, cheese, cream-filled bakery products, ready-to-eat foods.	Milk, paneer, khoa, street foods, meat products, and ready-to-eat foods.
Main cause of contamination	Improper food handling, cross-contamination, poor food storage, and infection in food handlers.	Improper sanitation, unhygienic. Contaminated raw milk.

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Major enterotoxin genes	***sea, sec*** and ***sed*** genes commonly reported worldwide.	Enterotoxigenic strains carrying ***sea*** and ***sec*** genes frequently isolated from dairy foods.
Public health importance	One of the leading causes of bacterial foodborne intoxication worldwide.	Major emerging food safety concern due to antimicrobial resistance and poor monitoring.
Resistance to food processing and cooking	Enterotoxins are heat stable and can survive cooking temperatures.	Similar concern in improperly stored cooked foods and dairy products in India.
Risk	Children, elderly, and immunocompromised individuals are highly susceptible.	Increased risk in densely populated areas with inadequate food safety practices.

Antibiotic resistance (AMR) in *Staphylococcus aureus*

Apart from foodborne illnesses, the emergence of antimicrobial-resistant strains, such as MRSA, becomes a safety concern to food industry. These resistant strains reported to enter the food chain through infected animals, contaminated processing area or food handlers. The resistant strains of *Staphylococcus aureus* pose serious public health and demand for strict food safety guidelines. Resistance to antimicrobials in *Staphylococcus aureus* is one of the most serious complications affecting health on a worldwide scale. The MRSA strains have the *mec*A gene that makes them to produce proteins interfering with the proper work of β-lactam antibiotics. Incorrect use of antibiotics in human health care and animal agribusiness is the reason for evolution of MRSA strains. Resistant strains of *Staphylococcus aureus* have been recovered and reported by numerous studies in dairy products, chickens, pigs, and beef. Antibiotic resistance in foodborne *Staphylococcus aureus* is a critical public health emergency, as the survived resistant strains can transmit their genes to other hazardous bacteria present in the environment and human and animal gut.

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Methods of *Staphylococcus aureus* detection

Staphylococcus aureus detection and strain identification is critical for monitoring food safety and responding to any outbreaks. There are various methods used for *Staphylococcus* isolation from different food samples, followed by their identification.

(i) Traditional culture method for isolation of organism

Methods involving use of selective media such as MSA (Mannitol Salt Agar) and Baird-Parker Agar for isolation of *Staphylococcus aureus* and presumptively identified by colony morphology and growth pattern. Further identification is performed by gram staining and microscopic observation.

(ii) Biochemical tests

A series of biochemical tests are performed to determine the biochemical profiles of *Staphylococcus aureus*. The biochemical tests results aid in next level confirmation of isolates. Standard biochemical test results for typical *Staphylococcus aureus* is as follows; positive to catalase test, coagulase test, methyl red test, voges-praskaur test, urease and mannitol fermentation and negative to indole test and oxidase test.

(iii) Molecular assays

Polymerase Chain Reaction (PCR), real-time PCR, various isothermal amplification assays, whole genome sequencing are methods used for detection, identification and characterization of *Staphylococcus aureus* at genomic level. Molecular assays are rapid and provide accurate detection. Commonly genes targeted for *Staphylococcus* identification are species-specific *16S rRNA*, *nuc*, enterotoxin genes, *mec*A gene (MRSA strains).

(iv) Immunoassays

Enzyme linked immunosorbent assays (ELISA) and latex agglutination tests used for toxins and bacterial surface antigens.

(v) Advanced detection techniques

Advanced techniques such as Real-time PCR, biosensors, Mass Spectrometry using MALDI-TOF technology, and next generation sequencing can also be used for detection of *S. aureus* in different samples.

Prevention and Control

Effective prevention of *Staphylococcus aureus* poisoning relies on strict adherence to hygienic protocols across of the food chain. Basic prevention measures include; good personal hygiene among food handler, proper cooking and refrigeration of foods, proper cleaning of food processing equipment, routine monitoring of dairy animal for mastitis and other diseases,

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judicial use of antibiotics in livestock production *etc*. In future, prevention and control measures should focus on research studies on following areas;

a) Development of user-friendly and affordable detection methods like loop-mediated isothermal amplification assays, rapid PCR, lateral flow assays for rapid detection of foodborne pathogens and better surveillance of foodborne illnesses.
b) Development and adoption of advanced food-safety monitoring systems, risk analysis and strengthen hazard analysis critical control points (HACCP) to improve food quality.
c) Development of improved hygiene and food handling practices and guidelines for strict adherence.
d) (d) Strengthen food safety regulations like development food safety standards, regular inspection and auditing and enforcing labeling and traceability.
e) Development of biofilm control strategies like anti-biofilm agents to discourage surface attachment of biofilm producing foodborne pathogens.
f) Control of emergence of AMR strains by following antimicrobial stewardship strategies, rational use of antibiotics, monitoring presence of MRSA in foods, developing alternative antibiotics-free treatment methods like bacteriophage-based therapies, use of herbal extracts and plant derived antimicrobials, encouraging use of probiotics *etc*.
g) Identification of virulence factors/toxins and their pathogenicity in host.
h) Implementation of one- health approach for integrated monitoring of transmission of foodborne pathogens in humans, animals, environment and food/food chain.
i) To create public awareness on food safety.

Conclusion

Staphylococcus aureus is the leading cause of foodborne intoxications. The capacity to produce heat stable enterotoxin, survivability in unfavorable and harsh environments and increasingly emergence of antimicrobial-resistance strains make *Staphylococcus aureus* a formidable hazard to food safety and public health. The growing evolution to multidrug resistant, such as methicillin-resistant *Staphylococcus aureus*, has further aggravated the food safety issues. Poor cleanliness, unhygienic food handling methods, and inappropriate storage conditions are primarily cause food contamination. Routine monitoring of food samples for detection of advanced detection tools, strict adherence to hygienic ways during food processing, storage and distribution, timely report of food illnesses etc. can be used for prevention and control of *Staphylococcus aurues* borne food illnesses.

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