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Novel Approaches in Food Microbiology: Assuring Food Safety and Public Health

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Abstract

While the cases of food borne infections, intoxications or the toxi-coinfection are nowadays well understood in many countries through the development of various isolation and enumeration means involving cultural, serological or molecular approaches, the root cause identification of food poising as well as the depiction of the food borne disease onset still needs huge advancement. A number of researches on food microbiology unraveled the food borne microorganisms and their associated pathogenesis till date; however, understanding of an accurate dataset regarding these food borne pathogens and the associated virulence factors is limited only to the limited developed countries capable of conducting advanced research on food safety issue. Certain essential aspects like the involvement of quorum sensing in food borne bacterial pathogenesis, the use of molecular tools and microbial biotechnology in food microbiology, application and understanding of genomic database, use of nanotechnology to detect the food borne pathogens, etc. are emerging to resolve the complications associated with food safety. Current review, in a bit brief way, discussed all these advanced approaches to disseminate the knowledge among the food microbiology professionals working especially in the developing countries like Bangladesh with the goal of maintaining the food safety as well as to regulate the mass public health condition.

Keywords:* *Food borne microorganisms; Food safety; Quorum sensing (QS); Microbial food biotechnology; Genomics; Nanotechnology; Public health

Introduction

An array of microorganisms has long been known to be of major importance in the food industries, from public health perspectives as well as for the biotechnological applications. Despite the ongoing development in the serological and molecular methods in food protection consideration over the traditional cultural methodology, the assurance of food safety and quality is still an essential issue as well as has appeared as a major confront at present time urging more effective microbial controls along the food production chain. Indeed, foods are usually prone to microbial attack (mostly by *Salmonella spp.*, *Campylobacter jejuni*, *Escherichia* strains including the *Shiga* toxin-producing *E. coli*-mostly the O157 serogroups, *Listeria monocytogenes*, *Vibrio spp.*, *Clostridium botulinum*, *Bacillus cereus*, *Penicillium expansum*, *Alicyclobacillus* *acidoterrestris*, *Wallemia spp.*, *norovirus*, *Cryptosporidium parvum*, *Giardia intestinalis and Trichinella spiralis*) which is actually suggestive but not always align the diagnostic results [1].

Due to foodborne hazards, public health concerns have been projected due to several foodborne pathogenic microorganisms mostly the toxigenic *Escherichia coli*, *Salmonella spp.*, *Shigella spp.*, and *Campylobacter spp.*, *non-typhoidal Salmonella enterica* (NTS), *Listeria spp.*, *Yersinia spp.*, and *Staphylococcus aureus* [2]. Conventional microbial control technologies (replying on chemical exposure, application of radiation, and thermal approaches) have been noticed to pose some major drawbacks like the degradation of quality and texture of the food items; high energy cost; wastage of foods; occupational and health hazards [3,4]. Therefore, the chemical-free approaches rise with its popularity among the consumers and hence pondering to develop novel, more efficient, sustainable, and low-cost anti-microbial methods [5].

The availability of safe food items is probably the most important global issue as well as it is challenging for the corresponding food authorities and the food industries [3]. The frequency and the dreadful impact of the foodborne disease are globally fatal with significant morbidity. Progression in food safety research around the globe is projecting the total knowledge of the foodborne microorganisms as well as the associated disease onset. Besides the wet-lab experiments, the construction of food safety based databases has drawn a huge improvement in the field of food microbiology. The present review attempted to concentrate on the ongoing application and necessity of involving the advanced approaches currently employed globally.

Disrupting the Quorum Sensing (QS) pathway: A metabolic approach

Food spoilage takes place principally due to cell-to-cell communication among the foodborne pathogens, a phenomenon known as quorum sensing (QS) [6]. Several studies pondered the bacterial QS system to be strongly linked to the biofilm formation followed by foodborne disease onset [7]. A number of QS signaling compounds have been reported to be present in different food items in the association of the dominance of *Pseudomonas spp.*, enteric bacteria, and Lactic Acid Bacteria (LAB) [8,9]. Thus, the information on the QS system would aid in developing approaches for disrupting such cell-to-cell communication systems; and hence preventing the spoilage network possible through controlling the expression of the genes encoding the virulence factors required to disseminate the foodborne diseases within hosts as shown in **FIG. 1** [6,10]. For cell-to-cell communication with the concomitant virulence factor production, bacterial cells have been reported to employ several classes of signaling molecules namely the N-acyl homoserine lactones (AHLs, also called autoinducer-1 or AI-1, produced by Gram-negative bacteria), a furanosyl borate diester (a universal signal for interspecies and intraspecies communications), also known as autoinducer-2 (produced by both Gram-positive and Gram-negative bacteria), the autoinducer-3 (AI-3, serving as the QS signal for enterohemorrhagic *Escherichia coli*), the autoinducing peptides (AIPs), produced by Gram-positive bacteria, and the 2-heptyl-3-hydroxy-4-quinolone (PQS) in *Pseudomonas aeruginosa* [6,11,12]**.** Development of the Quorum-sensing inhibitors (QSIs) in order to target and block the synthesis of the cell signaling molecules would also be helpful to prevent the biofilm-forming food spoilage bacteria as evident from *Bacillus spp.*, *Enterococcus spp.*, *Staphylococcus spp.*, *Streptococcus spp.*, *Streptomyces spp.*, *and Rhizobium spp*. [6,10]. QSIs can be regarded of significant values in terms of food safety through their capacity to regulate virulence factors of pathogens with the biofilm formation traits (**FIG. 1**). This approach is well known to identify the virulent microorganisms especially within the meat (isolation of *Enterobacteriaceae* strains, *Aeromonas hydrophila*, *Yersinia enterocolitica*, *Pseudomonas fragi*, *E. coli* O157:H7, Lactic acid bacteria) and vegetable products (isolation of *Enterobacteriaceae* strains, *Pseudomonads*, and *Vibrionaceae* strains, *Yersinia enterocolitica*, *E. coli* O157:H7) [6].

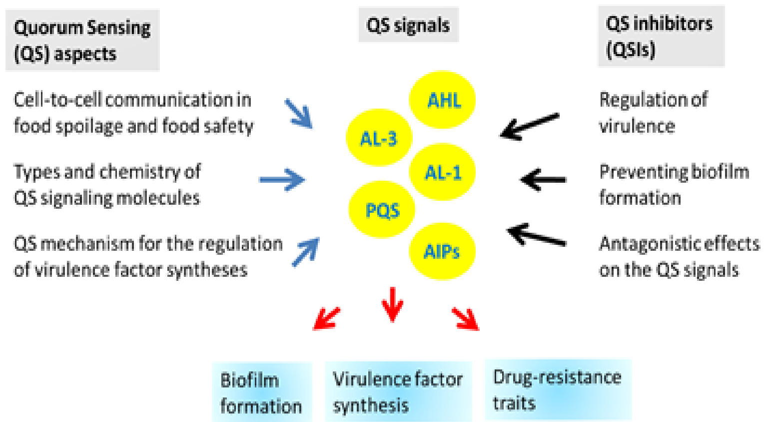

FIG. 1. **Quorum sensing (QS) aspects in food safety management**.

With the aid of different QS signals like N-acyl homoserine lactones (AHLs, also called the autoinducer-1 or AI-1), furanosyl borate diester, the autoinducer-3 (AI-3), the Autoinducing Peptides (AIPs), and the 2-heptyl-3-hydroxy-4-quinolone (PQS), food spoilage may take place due to the strong cell-to-cell communication among the foodborne pathogens triggered by those signals. A number of QS signaling compounds are actually present in different food items, and hence the information on the QS system would help in developing approaches for disrupting the cell-to-cell communication systems and thereby preventing the food spoilage. Such an ingenious mechanism can be induced by the Quorum-Sensing Inhibitors (QSIs) which target and block the synthesis of the QS signaling molecules.

Molecular Tools and Microbial Food Biotechnology: The Prime Approach

The use of microorganisms in food industries has long been practiced because of their fermentative metabolism, and due to their health-promoting effects; i.e., the probiotic products [13]. As commonly known, the commercial starter and secondary cultures (of bacteria, yeasts and molds, produced in the industrial-scale bioreactors) are applied in the modern fermentation-based food processing. The cultures, typically consisting of a single type of microorganisms or a complex consortium of microorganisms are formulated (by possible genetic- or metabolic engineering) to achieve the desired features and quality of the finished product(s) **(FIG. 2)**. The microbial diversity in food items has already been analyzed using High-Throughput Sequencing (HTS) approaches and by several Next-Generation Sequencing (NGS) technologies [14].

However, an interesting molecular approach using the genome-scale reconstruction of metabolic networks combined with constraint-based modeling (CBM) became widely acceptable which was basically projected through the genomics data of the organism of interest; and further converting the network reconstruction into a mathematical model known as the genome-scale model (GEM) as shown in **FIG. 2** [13,15]. Such an approach can be used to assess the metabolic potential of industrial strains used in food processing, and to understand the existing interactions in microbial consortia and the simulating community phenotype which are actually required for designing culture blends for food fermentations [13,16,17]. Very recently, an approach namely the RedCom approach, regarding the building of appropriate microbial consortium for food fermentation technology, has been introduced where reduced community models were constructed from net conversions of the linear single-species models [16].

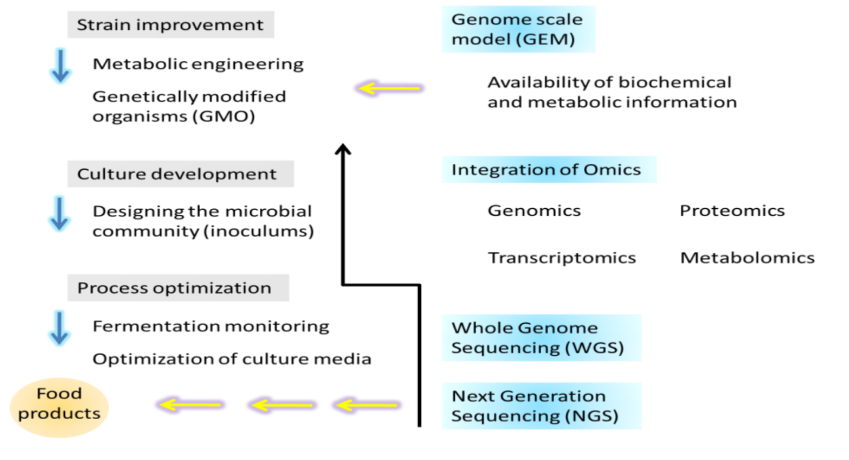

FIG. 2. **Application of molecular tools and the implementation of microbial food biotechnology for food safety.**

The knowledge on the Constraint-Based Modeling (CBM) helps in understanding the appropriate strain development for the industrial food item production accompanied by the microbial culture improvement and the bioprocess (fermentation) optimization in order to achieve safe food products [13]. The integration of genome-scale model (GEM, where the comprehensive information is available) and CBM together with the omics data analysis (through the relevant databases) further ponders to the global qualitative and quantitative microbial metabolic traits within a given environment (i.e., in a chemostat or in an industrial fermenter) to achieve high-quality products.

Knowledge and Applications of Genomics in Food Safety: The Database Approach

As shown in **FIG. 2**, the whole genome sequencing (WGS) to provide detailed characterization of foodborne pathogens (as evident from *Salmonella spp., Escherichia coli, Listeria spp., Campylobacter spp.* and *Vibrio spp.*), and the applications of shotgun metagenomics for their taxonomic profiling and the possible drug-resistance traits have emerged as novel approaches in the field of food safety [18,19]. The genetic make-up of diverse pathogens causing foodborne illness will doubt go a long way to resolve the public health issue related to food-related problems. Such a genomic approach is expected to function as the foodborne disease outbreak detection, identifying the reason for food contamination, accumulating all the virulence traits, etc. [19]. Thus the new technologies and tools in genomics and metagenomics, and obviously about bioinformatics in food microbiology would be a great impact to ensure food safety as well as maintaining public health sustainability [18,20].

Application of Nanotechnology in Food Safety: Another Novel Approach

Over the current food processing methods like heating, freezing, refrigerating, UV or γ-radiation, filtration, drying, use of chlorine-based compounds, ozone, hydrogen peroxide, etc., the novel approach of nanotechnology (i.e., the nano-enabled technologies including antimicrobial surfaces/packaging, sensors and biocidal platforms for food safety applications) has appeared as a promising technology for the sake of the required consumer safety and the quality of foods [3]. The use of antimicrobial food contact surfaces and surface coatings using engineered nanoparticles is really innovative in terms of the rapid detection of the presence of pathogens or other substances [3]. Such nanoparticles mostly include silver (Ag), zinc oxide (ZnO), Titanium oxide (TiO_2), cerium oxide (CeO_2), bismuth vanadate ($BiVO_4$), etc., which indeed function as the nano-enabled sensors for pathogenic detection as well as during food packaging with improved food protection properties [3,21,22]. Nanoscale silver is, in fact, a very useful anti-bacterial metal that can completely inhibit bacterial attachment to any surface as well as can inhibit biofilm formation [23]. Interestingly, the natural antimicrobial extracts alternative to the above-mentioned chemicals are also used in nanotechnological applications: the nano-encapsulated immobilized cinnamaldehyde and the soybean polysaccharide nano-emulsion weres found to impart antibacterial activity against *E. coli* [24]. The nano-emulsion on an edible chitosan coating and the pectin/papaya puree/cinnamaldehyde nano-emulsions were found active against *E. coli, L. monocytogenes* and *S. enterica* [3,25].

Newer Approaches for Food Safety: Bangladesh Aspect

As discussed above, besides exercising the traditional culture-dependent methodologies involving the molecular methods, the methodological approaches in food microbiology are now in huge practice of focusing on (i) the construction of essential databases; i.e., concentrating on the genomics and bioinformatics of the foodborne microorganisms; and (ii) the predictive investigation of the possible foodborne disease outbreak accompanied with the rapid detection and monitoring of foodborne pathogens through the possible applications of the advanced molecular biology, microbial biotechnology and the involvement of nanotechnology [3,13,14,16-19,26]. However, in Bangladesh, such technological advancements are still lacking to a huge extent since mostly the experiments here are the traditional culture-dependent. The study of food microbiology is limited to the isolation and enumeration of the heterotrophic microorganisms as well as the detection of specific pathogens (sometimes accompanied by their drug-resistance traits) using the selective cultural and biochemical methods. Not only in the research laboratories but also in the food industries basically rely on such traditional procedures. Some of the molecular studies involving specific virulent gene detection have been reported so far in this country but that's actually to a primitive level in context to the complete objective of maintaining the food safety let alone the predictive analysis of foodborne disease onset [27,28]. Resource-poor settings, financial constraints to set up the essential logistics, lack of required expertise may account for such an ill situation of current research on food safety in Bangladesh. Both the regulatory authorities (or the legislative bodies) and our food researchers, as well as the professionals working in food industries, may pinpoint these problems for the possible progression in the study of food microbiology in accordance with the globally ongoing advanced approaches.

Conclusion

Advancement in food safety research and studies around the world is really escalating the in-depth knowledge of the foodborne pathogens together with the concomitant disease complications. The fine-tuned application of genetic engineering in the food microbial biotechnology, sensitive procedures like the whole genome sequencing or the next-generation sequencing, constructing the phylogeny of the foodborne pathogens, creating the databases related to foodborne microorganisms and the associated hazards through the application of "Omics" concept (i.e., the genomics and bioinformatic analyses), precise detection of the foodborne pathogens using nanotechnology; and predicting the possible foodborne disease have emerged in many developed countries to maintain the food safety along with the sustainable consumer safety as well. In perspective of Bangladesh, such high technological throughput along with the food industries and the food research laboratories would be quite challenging because of some limitations like the required expertise to handle these tools as well as the financial deficit for capacity building to conduct such types of advanced studies. Yet the concurrent knowledge on the ongoing approaches to maintain food safety would increment our researchers and professionals to design their experimental strategies regarding food safety in the future.

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Conflict of Interest

The author declares no conflict of interest.

Author Contributions

Rashed Noor for conceptualization, original draft preparation, review and editing.

Ethical Approval

This article does not contain any studies with human participants or animals performed by the author.

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