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REVIEW

The role of microbes in food security

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Food is of vital importance for human life. Consumers prefer healthy, safe and quality food. In recent years, consumers are prone towards ready to eat, ready to serve and ready to cook foods. Therefore, to maintain the long shelf life of these foods without affecting their sensory attributes, the preservation of foodsis a major challenge for producers. Food moves through many levels, from production to storage domains. During these phases, several physical, chemical and microbiological factors are responsible for deterioration in quality. Spoilage of food is a threat to food security. In this article, the role of different type of microbes in food processing, methods for detecting spoilage and preventive measures have been explored. The beneficial functions of microbes have also been highlighted in this article.

Key words: Food quality, microbes, spoilage, preventive measures

INTRODUCTION

Despite the technological advances achieved in recent decades, changes in consumer lifestyles have made it necessary for the food industry to meet apparently contradictory market demands. Consumers now expect superior sensory quality food products and having notable functional and nutritional properties in combination of a traditional and healthy image with guaranteed safety. To fulfill the consumer demands, industries are processing raw materials into newer products continuously in a dynamic mode.Good quality food which retains nutrients and least chemical residues are expected by consumers. Motto behind the processing of food is to improve its digestibility and palatability as well as to provide its supply continuously. With the innovative product processing, it is also necessary to preserve the shelf life. Keeping quality of food product can be deteriorated by various factors such as physical, chemical and microbial. Spoilage of food is associated with the off-flavor development, breakage of texture, loss of nutritional parameters and discoloration. Therefore, prevention of spoilage and preservation of food products have huge global challenges.

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Microbial deterioration is one of the major reasons behind the spoilage and it is a mandate to adopt appropriate preventive actions so that food security is not jeopardized. Food spoilage microbes mainly include mould, bacteria and yeasts. Factors that enhance the growth of microbes include availability of nutrients, water, pH, oxygen levels etc. Developing countries generally face risks of food borne parasites and mycotoxins as compared to developed countries (Grace, 2015). Pathogenic threats to food industries are various microbes like *E. coli, Campylobacter* spp., *Listeria monocytogenes, Salmonella* etc. Provision of food which is safe and free from pathogenic microbes is an important goal of food industries.

CLASSIFICATION OF MICRO-ORGANISMS

Various microbes responsible for food deterioration are categorized as follows:

a. Yeasts

Yeasts are a subset of fungi, including molds and mushrooms. They are usually single-celled organisms adapted to life in specialized, usually liquid environments and do not produce toxic secondary metabolites, unlike some molds and mushrooms. Yeasts can grow with or without oxygen (optional) and are known for their beneficial bread and alcoholic beverages fermentation. They often colonize high-sugar or salt foods and help spoil maple syrup, pickles and sauerkraut. Other targets are fruits and juices with a low pH, and some yeasts grow on meat and cheese surfaces as well (Rawat, 2015). Spoilage yeast include *Zygosaccharomyces* spp*, Debaryomyces hansenii, Dekkera/Brettanomyces* spp*, Candida* spp etc.

b. Molds/fungi

Molds are filamentous mushrooms that do not produce large fruit bodies such as mushrooms. Molds are very important for the recycling of dead plants and remains of animals in nature, but they also attack a wide variety of foods and other human useful materials. They are well suited to grow on solid substrates and through them, generally producing airborne spores and require oxygen for their metabolic processes(Rawat, 2015). Spoilage moulds includes species of *Mucor* spp*, Rhizopus* spp*, Penicillium* spp*, Byssochlamys* spp*, Aspergillus, Fusarium* spp.

Table1. Stages prone to outbreaks of microbial contamination

Microbial contamination at different stages	Effect(s)	References
Raw material contamination	Inappropriate suppliers' processes or wrong storage may cause microbial contamination. Fresh vegetable products used as infection sources	Wu 2012; Lehto *et al.* 2011; Gustavsson *et al.*2011
Contamination during packaging of food	One of the main potential sources of pathogenic microorganisms is air combined with packaging in the food supply chain	Harris *et al.*2014
Food Refrigeration contamination	Inappropriate cooling systems can cause microbial contamination, which can lead to a large loss of food products	James *et al.*2006; Sampers*et al.*2008; Carpentier *et al.*2012.
Transportation and food service operations risk	Inappropriate transport services can cause microbial contamination. The handling of products at the end of the destination or at incorrect tem peratures can cause microbial contamination and loss of food.	Gitahi 2012; Hassouneh *et al.*2012; Linton and McSwane 2013

c. Bacteria

Bacteria that form spores are usually associated with the spoilage of heat-treated foods, as their spores can survive high processing temperatures. These Gram-positive bacteria may be strictly anaerobic or facultative (with or without oxygen capable of growth). Some spore formers are thermophilic and prefer to grow at high temperatures (up to 55°C). Some anaerobic thermophiles produce hydrogen sulphide (*Desulfoto maculum* spp*)* and others produce hydrogen and carbon dioxide (*Thermoanaerobacterium* spp*)* during the growth of canned / hermetically sealed foods kept at high temperatures, such as soups sold in sales equipment (Rawat, 2015). Spoilage bacteria include thermophiles (*Bacillus* spp *and Geobacillus*spp); mesophilic (*Bacillus* spp); Psychrotropic (*Clostridium* spp).

Microbial contamination can occur from farm to fork. Different stages can be exposed to microbial attack (Table 1).

DETRIMENTAL EFFECTS OF SPOILAGE MICROBES

Contaminated food could be responsible for several health hazards such as food poisoning, nausea, diarrhea etc. Various microbes proliferate if they get desirable environment for their growth thereby vitiating the food leading to serious illness (Table 2).

Spoilage of different foods

Food which are perishable in nature expose mainly to the microbial attacks include fresh fruits and vegetables, milk, poultry eggs etc. which are summarized as below (Table 3).

Table2. Diseases induced by Micro-organisms

Disease	Microbe	References
Staphylococcal poisoning	*Staphylococcusaureus*	Danielsson-Tham, 2013
Vibrio infection	*Vibrio vulnificus*	Crim *et al.* 2014
Mycotoxin poisoning	*Aspergillus flavus*	Bhat *et al.*2010
Enterohemorragiccollitis	*E. coli O157:H7*	Yoon and Hovde, 2008
Cholera	*Vibrio cholerae*	Bhunia, 2008
Escherichia gastroenteritis	Enteropathogenic and enterotoxigenic *E. coli*	Robinson and McKillip, 2010
Non-hemorrhagic colitis	*E. coli O26:H11*	Mathusa *et al.* 2010

Table3. Spoilage of different foods

Food	Spoilage microbe	References
Fresh fruits and vegetables	*Rhizopus, Erwinia E. coli* ,	Abadias*et al.* 2008; Anonymous, 2016
Various fruit products and citrus juices	*Saccharomyces cerevisiae, S. bayanus*	Stratford *et al.*2014
Milk/cream	*Alcaligenesviscolactis, Micrococcus, Enterobacter, Lactobacillus, Streptococcus, Bacillus* spp.	Laws and Marshall, 2001
Poultry eggs	*Alcaligenes, Pseudomonas Salmonella enteritidis*	Cerveny *et al.* 2009; Kamala and Kumar, 2018
Fresh meats	*Alcaligenes, Clostridium, Proteus vulgaris, Pseudomonas fluorescens*	Nychas *et al.* 2008
Fish	*Alcaligenes, Pseudomonas, Flavobacterium*	Sivertsvik *et al.*2007
Beans	*Aspergillus ochraceus*	Zain, 2011
Corn and corn products	*Fusarium spp.*	Jackson *et al.* 2013
Nuts and dried fruits	*Penicillium*spp, *Rhizopus* spp, *Mucor* spp and *Cladosporium* spp	Overy*et al.* 2003 Tournas *et al.* 2015

Mechanism of spoilage by microbes

Foods being rich in carbohydrates, proteins and lipids are very nutritious both for microbes and humans. A small number of microorganisms are often responsible for loss of quality based on food characteristics, environmental conditions and microorganism interactions (Petruzzi *et al.* 2017). Microorganisms that can grow in food have developed biochemical mechanisms to digest food components and provide energy sources for their own growth (Sperber, 2009). results in a wide The transformation of the available compounds range of end products affecting sensory, chemical and physical properties of the food (Howell, 2016).

Range of possible compounds produced depends not only on the genetic capacity of the microorganism concerned, but also on the intrinsic characteristics of the product and the extrinsic characteristics of the handling and storage environment, which can significantly change biochemical pathways (Benner, 2014; Howell, 2016). Deterioration of food induced by spoilage of microorganisms during storage and distribution has a huge impact on food quality and shelf life, and pathogenic microbes found in food may cause a variety of infections and/or intoxications (Villalobos-Delgado *et al.*2019). A variety of microbes that use food as a carbon and energy source mediate chemical reactions that cause offensive sensory changes in foods. These organisms include prokaryotes (bacteria) and eukaryotes, (molds). Some microbes are commonly found in many types of spoiled foods, while others are more selective in the foods they consume; multiple species are often identified in a single spoiled food item, but one species (a specific spoilage organism, SSO) may be primarily responsible for the production of off odor and flavouring compounds. There are often a series of different populations within a spoiling food that rise and fall as different nutrients become available or exhausted. According to Scallan *et al.* (2011), approximately 48 million cases of food borne disease occur annually, and out of which 128,000 lead to hospitalization and 3,000 deaths. There are outbreaks of disease caused by contaminated foods, which surprisingly include fresh fruits and vegetables (Berger *et al.* 2010; Painter *et al.*2013).In order to prevent microbial colonization, living plants and animals have structural and chemical defenses, but once they are dead or dormant, these systems deteriorate and become less effective. Microbes start to break down food molecules for their own metabolic needs. First they use sugars and easily digestible carbohydrates followed by plant pectins. Proteins are then attacked and characteristic smells such as ammonia, amines and sulphides are produced by volatile compounds.

Effect on world Economy

The enormous loss of fruit and vegetables is alarming and poses a serious threat to global food security. Many international conferences have discussed the enormous economic loss to farmers and the reduction of gross domestic product (GDP) in developing countries. Despite considerable efforts, even in advanced countries, microbiological security seems as remote as ever. Death, misery, economic losses and civil claims on behalf of survivors of foodborne diseases are exacerbated by economic losses caused by food spoilage. Food loss is a waste of invaluable production resources such as land, water, energy and inputs. In addition to the loss of economic value of the food produced, the production of food that is not consumed leads to unnecessary carbon-di-oxideemissions. Economically preventable losses of food have a direct and negative impact on farmers' and consumers' incomes. Since, many smallholder farmers live on food insecurity margins, reducing food losses could have an immediate and significant impact on their livelihoods. For poor consumers (food insecurity or households at risk), access to nutritious, safe and affordable food products is clearly a priority. The exact figures of the total economic losses due to food spoilage is unclear, but it is evident that this poses an enormous financial burden measured at 1.3 billion tons per year by FAO (Cichello, 2015).Generally, about 30 % fruits and vegetables are rendered unfit for consumption due to spoilage after harvesting. India annually produces fruits and vegetables of the value of about Rs. 7000 crores and wastage may be of the order of Rs. 2100 crores (Rawat, 2015).

ANALYTICAL METHODS FOR DETECTION OF MICROBES

Food industries generally need rapid analytical methods or tools to quantify indicators of food spoilage in order to determine the processing appropriate for their raw materials and to predict the remaining shelf life of their products. The inspection authorities need reliable control methods. Therefore, it is essential to have valid methods to monitor freshness and safety in order to ensure quality, regardless of the point of view of the consumer, the industry, the inspection authority or the scientist (Nychas, 2011; Buszewski *et al.* 2017).

Rapid Techniques

Some interesting analytical approaches to the rapid and quantitative monitoring of food spoilage have been proposed. It includes biosensors (enzymatic reactor systems), electronic noses (array of sensors), Fourier transform infra-red spectroscopy (FT-IR), integration of the FT-MIR Attenuated Total Reflectance bio-sensors or other bio-sensors in tandem with an information platform and development of an 'expert system' to automatically classify the sensory input into a 'diagnosis' based on extracted pre-processing features. The application of advanced statistical methods (discriminant function analysis, clustering algorithms, chemo-metrics) and intelligent methodologies (neural networks, fuzzy logic, evolutionary algorithms and genetic programming) may be used as qualitative rather than quantitative indices since their primary aim is to distinguish objects, and groups or populations. This is an unsupervised learning method (Ellis and Goodacre, 2006). The recent development of high-performance sequencing has led to a deeper analysis of ecosystems of food microbials. These approaches, mainly focused on 16S rDNA confirmed previous studies on the nature of bacteria found in food using classical cultural methods. Furthermore, the data obtained from the direct analysis of DNA extracted from food matrixes enabled a better description of ecosystems at genus or even species level, and also showed that the involvement of some species in the spoilage of food could be underestimated (Remenant *et al.* 2015).Intelligent packaging determine microbial quality through indicators within the package and produced metabolites during microbial growth. Indicators used inside or outside the cover (Pavelková, 2012).

Polymerase Chain Reaction (PCR)

Some methods such as enzyme-linked immunosorbent testing or polymerase chain reaction (PCR) have already become classic methods of identification. The development of PCR protocols and sequencing tools has provided a significant amount of information that has already been deposited in public databases and is freely available. In contrast, the development of rapid and high sensitivity techniques, such as real-time PCR (qPCR), DNA microarrays and biosensors, has led to the replacement of traditional methods in the field of bacterial identification for clinical diagnostics and the food sector. In addition, spectroscopy of Fourier transforms infraredspectrometry and spectroscopy of Raman have also been examined for their potential to assess food spoilage (Argyri *et al.* 2011). At the same time, proteomic tools for the identification of microorganisms have been introduced, such as mass spectrometry (Quintela-Baluja *et al.* 2014).

Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)

CRISPR technologies have developed groundbreaking methods for editing genomes. The development of Cas proteins with alternate behaviors has now allowed flexible and reliable nucleic acid detection methods. Recent reports using these modern CRISPR –Cas techniques demonstrate their promise for delivering low-cost and realistic diagnostic tools for pathogen and disease detection (Sashital, 2018). Gootenberg*et al.*(2017) have developed SHERLOCK(Specific High Sensitivity Enzymatic Reporter Unlocking) which combines isothermal amplification of nucleic acid sequence with Cas13a-based detection platform for detection and diagnosis.

Prevention of food spoilage

Microbial preservation of food can be done by keeping out microbes out of the food, removal of microbes from contaminated foods and preventing their growth. Different processes and methods have been used to prevent food and beverage microbiological spoilage. In fact, food preservation can be defined as the process of treating and handling food in a way that stops, controls or greatly slows down spoilage and, of course, minimizes the possibility of food-borne disease while maintaining the best nutritional value, texture and flavorIn order to be effective, preservation must be equal to the microbial “challenge” presented by the food products. Different processes have been used to prevent the microbiological spoilage of food and beverages, including low temperature storage and heat treatment. In order to suppress spoilage microorganisms, the use of a rich carbon dioxide atmosphere as part of a modified atmosphere packaging system is also effective. Many food products show perishable nature and require protection against spoilage during their preparation, storage and distribution to provide them with the desired shelf life. Since food products are now often sold in areas far away from their production facilities in the world, the need for extended safe shelf life for these products has also increased. The development of food preservation processes was driven by the need to increase shelf life of food materials. Food preservation is an ongoing fight against microorganisms that spoil or make the food unsafe. Several food preservation systems, such as heating, refrigeration and antimicrobial compounds, can be used to reduce the risk of food poisoning outbreaks; however, adverse changes in organoleptic characteristics and loss of nutrients are frequently associated with these techniques.

Contamination can be prevented by proper cleaning and sanitation. Sterilized water should be used at any level of food processing. The design of the equipment should be carefully done to avoid microbial growth in any part of the equipment. The detection of microbial growth would be one effective way to prevent microbial contamination in industries.Chemical disinfection procedures using ozone are used to remove microbes in solid food products. Thermal and non-thermal techniques, such as microwave heating, pulsed electrical field technology, high-pressure processing, high-light technology, Ohmic heating, ultrasonic and pulsed X-ray technology, have recently been used in the food industry(Chatterjee and Abraham 2018). Packaging plays a key role in ensuring the quality of the food from any harmful changes. In recent years, apart from many plastics, several additives have also been used to improve food safetywhich include plasticizers, antioxidants, antimicrobials, light stabilizers, thermal stabilizers, lubricants, antistatic agents and slip additives.

BENEFICIAL MICRO-ORGANISMS

Pathogenic microbes live and promote growth in equipment used in the food industry, contributing to the introduction of pathogens into food production, as well as to the processing cycle (Chatterjee and Abraham, 2018). However, microbes are extensively used in food industries, biotechnology and modern genetic engineering. Micro-organisms are not only the reason of food spoilage but also they are reason for preservation of food. There are certain microbes which helps the food to enhance its shelf life. Microbes for preservation are involved in various biochemical processes such as fermentation which is the process that has been employed for years to preserve the food for consumption over long period of time without refrigeration (Quave and Pieroni 2014). Different fermented foods are used to improve the shelf life of perishable food items such as kimchi, shalgam etc. Kimchi is a traditional dish of Korea. It has high concentration of lactic acid and salt which improve its keeping quality (Kim, 2013).Fermented fish products are famous among the people of Thailand because of its high digestibility and low fat content. Shalgam is a lactic acid fermented beverage in Turkey, which is made by using the process of fermentation of black carrots and is rich in antioxidants, such as carotene and anthocyanin (Erten *et al.*2008). Gorani community in Albania used different fermented plants as food and medicine thereby ensuring food safety in their community (Quave and Pieroni 2014).

CONCLUSION

Microbes impact human life both in beneficial and detrimental ways. Spoilage microbes inflict colossal losses in agriculture and food production, which in turn affects the national exchequer. Thermal and non-thermal processes with variations and modifications can be used to eliminate spoilage microbes.Coating fruits and vegetables with biofilms are also in the fore.As the microbes are useful in different foods and biological sectors, researchers in the development of this domain are striving harder to harness the microbes for the welfare of the society and human race.

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