Chapter 3
Use of Microbe Free Contact Surfaces to Control Food Spoilage: A Step Towards New Food Technologies

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Introduction

Food safety is essential not only to meet the nutritional requirement but also to ensure its safe supply to needy people (Ahmed et al., 2022). Consumers are becoming increasingly aware and health conscious therefore the demand for healthy, safe, and good-quality food is increasing (Rawat, 2015; Odeyemi et al., 2020). In recent years due to the busy lifestyle, the demand and consumption of readymade foods have increased tremendously. To satisfy the expectations of the market the food sector is striving to develop methods for delivering safe, fresh, and healthy food to consumers (Albrecht & Smithers, 2018). Food processing is a group of techniques used to turn raw food into value-added food (Ravindran & Jaiswal, 2016). To produce branded, marketable food with consistency of quality a continuous supply of crops and animals is required (Drouillard, 2018). The concept of processing food started during prehistoric times, which includes roasting, smoking, steaming, and baking. Before industrialization, methods like canning and salting were also developed (Ghoshal, 2018; Joardder & Masud, 2019). Food processing techniques are shaping the modern world by ensuring food supply not only to general consumers but especially to space scientists, the army, and other explorers. (Hammond et al., 2015). These techniques help to increase the food shelf life and decrease food waste (Aday & Aday, 2020; Han et al., 2018). After the production of good quality food, its preservation is a major concern for the producers as from production to preservation the food is exposed to various

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F. Ahmad et al. (eds.), *Microbial Biotechnology in the Food Industry*,
https://doi.org/10.1007/978-3-031-51417-3_3

factors and its quality may quickly deteriorate due to chemical, physical, or microbial changes (Mastromatteo et al., 2010; De Corato, 2020; Zhao et al., 2022). Especially when the food comes in contact with various surfaces it may be exposed to such threats. Food may get contaminated when it comes in contact with surfaces carrying microbes bringing changes in food quality like off-flavor, loss of nutrients, discoloration, and deterioration of texture (Francis et al., 2012; Giannakourou & Tsironi, 2021; Uebersax et al., 2022). This may result in food spoilage which poses a widespread and significant threat to food security (Pitt & Hocking, 2022; Mc Carthy et al., 2018; Saeed et al., 2019; Singh et al., 2022; Wang et al., 2017; Yang et al., 2017; Zhao et al., 2022). At any given period during manufacturing and storage, food products may either carry a unique microbiota or is susceptible to growth by a certain group of microbes, which depends on their physical and chemical properties. Hence one can predict which bacteria may grow or predominate in a particular food (Anagnostopoulos et al., 2022; Ferrocino et al., 2022; Manthou et al., 2022).

The spoilage may be caused by the growth of an organism in food or through the formation of unfavorable metabolites and toxins (Boziaris & Parlapani, 2017). Microbial spoilage is the primary cause of food degradation, which needs to be controlled if the goal of food security is to be achieved (Gil et al., 2015). Microbes of all kinds including bacteria, protozoans, fungi, and viruses are responsible for food spoilage (Trevanich, 2022). Various factors include pH, temperature, moisture, and oxygen levels. Influence the growth of bacteria in food (Cheng et al., 2022; Perumal et al., 2022). The presence of pathogenic microbes causes what is known as foodborne illness and the toxins produced from microbes cause food intoxication along with financial losses (Abebe et al., 2020; Fung et al., 2018). Food-borne illnesses are a significant burden and challenge for public health around the globe (Cissé, 2019; Todd, 2020). Mycotoxins and parasites that spread through food are typically a problem in developing nations (Grace, 2017). Pathogens like *Salmonella, Listeria monocytogenes, E. coli,* and other pathogenic bacteria pose a health risk associated with food (Balali et al., 2020). Food industries need to minimize the chances of food contamination to ensure the delivery of safe food to consumers (Singh et al., 2022). In South-East Asia, 150 million cases of food-borne disease and 175,000 mortalities due to food-borne illnesses were reported in 2010. And 40% of this burden was carried by children under the age of 5 (Vidhubala Priskillal, 2019). An estimated 50% of the malnutrition is not caused by a lack of food or a poor diet but is rather due to insufficient availability of water and lack of proper sanitation facilities, lack of hygiene, inappropriate handling techniques, cross-contamination of cooked food with raw food and inadequately washed food, which can result in diseases and infections like diarrhea (Ekici & Dümen, 2019).

Since contamination through food contact surfaces (FCS) is a significant threat the decontamination of these surfaces is necessary to improve food health. Decontamination is the process of minimizing or eliminating microbes from objects, surfaces, devices, and environments so that they cannot contaminate food (Mota et al., 2021). Heat, steam, chemical solutions, gases, radiations, and several other techniques including high hydrostatic pressure, ultrasound, pulsed electric field, and pulsed light are used to prevent surface contamination (Sipos et al., 2021). These techniques help to reduce the chances of contamination but have some unavoidable disadvantages also. The approaches are limited due to safety issues, the sensitivity of the materials that need to be sterilized, a lack of effectiveness, and financial considerations.

Cold atmospheric pressure plasma technology enables multi-target microbial inactivation on surfaces, offering a promising non-thermal alternative to conventional techniques (Dasan et al., 2017; Rifna et al., 2019). These plasma processes provide a special combination of strong reactivity at moderate temperatures because of the non-equilibrium plasma discharges' non-thermal features, which is advantageous for treating temperature-sensitive substrates (Dasan et al., 2017). Non-thermal atmospheric pressure plasmas are used in a variety of applications like electrochemical sensors, preparation of functional surfaces, inactivation of micro-organisms in food and food contact surfaces, preparation of ready-to-eat food, biofilm degradation, and healthcare, etc. (Alonso et al., 2022). This chapter discusses the food contact surfaces and spoilage of food. Different procedures adapted for the decontamination of the food and the emerging technology.

Food Contact Surfaces (FCS) and Their Contamination

Food production involves various processes from production to the consumer level (Saini et al., 2021). During its production, the food comes in contact with various surfaces generally referred to as food contact surfaces (FCS; Addo Ntim et al., 2015). Examples of these surfaces include utensils, cutting boards, flatware, tables, highchairs, microwave oven, and refrigerators (Menini et al., 2022). The FCS is often contaminated by dirt, allergen, and pathogenic micro-organisms, and therefore to avoid contamination of food these surfaces must be cleaned and so it's better to sanitize (Rutala & Weber, 2018). More than 250 sources of foodborne illnesses have been found (Hassan, 2022). Several food quality standards have been implemented globally due to the rise in foodborne infections and illnesses (Maragoni-Santos et al., 2022). The microorganisms that attach to plant and animal tissue can affect food safety and spoilage (Chitlapilly Dass & Wang, 2022). Biofilms are developed on the surfaces, resulting in contamination (Sharma et al., 2022). The quality of food is at risk at each step of its production from harvesting or slaughtering to packaging till it reaches consumers (Kumar et al., 2022). Food spoilage is caused by a variety of microorganisms and is characterized by the emergence of off flavors, deterioration of texture, loss of nutritional components, discoloration, etc. (Giannakourou & Tsironi, 2021). The concern about the bio-deterioration of food is increasing in the food industry (Pandey et al., 2022). It is necessary to find effective and economic techniques, that are easy to use and do not affect the taste and nutritional value of food (Liu et al., 2022). Various raw foods like fish, meats, and poultry are prone to the growth of pathogenic bacteria which get transmitted to cooked, ready-to-eat and fresh food (Gálvez et al., 2010). Additionally, the food may contain certain toxins, spores, and allergens. The transfer of contamination can also occur through the dispersal of biofilm especially form contact surfaces (Sharma et al., 2022). Foodborne illness is the result of low maintenance, and poor hygiene during food preparation (Rifat et al., 2022). Sometimes using the same cooking utensil for both raw and ready-to-eat foods may lead to contamination (Sharma et al., 2022). The contaminated surface is responsible for the pathogen transfer commonly in domestic settings for example, the transfer of pathogens from raw meat to fresh fruits and vegetables after using the same contaminated equipment (Chea et al., 2022). Low maintenance during the storage of food (refrigerators, Ovens), and poor hygiene during food preparation (unwashed utensils, reuse of same surfaces for different foods) are some of the reasons behind foodborne illnesses (Schirone et al., 2019).

Microbial Risk Associated with Food at Different Levels of the Food Processing

The spoilage or contamination of food by undesirable microorganisms is one of the main threats to food (Misiou & Koutsoumanis, 2021). Food spoilage is a process that results in unfavorable or unsuitable changes to food, such as changes in flavor, smell, appearance, or texture, rendering it unfit for human consumption. And very often this occurs as a result of the biochemical activity of microorganisms (Sikorski et al., 2020). Microbes are the main reason behind food spoilage making it necessary to take preventive measures to control microbial growth in food (Gil et al., 2015). Bacteria, mold, and yeasts may cause various types of food spoilage depending upon the type of food, types of nutrients in food, its moisture content, pH (acidic, neutral, or alkaline), and oxygen levels, etc. (Azad et al., 2019). Food spoilage can occur due to microbial contamination at any stage of food processing or supply chain, like during food packaging, food storage, or transportation. During these processes, food may come in contact with microbes or pathogens if the contact surfaces are not sterilized. Contamination or spoilage of food results in various health hazards including food poisoning, nausea, and diarrhea. (Mohammad et al., 2018).

Contamination of Food by Microbial Biofilm

Poor hygiene during food preparation is a major contributing factor to foodborne illnesses (Kamboj et al., 2020). The ability of microorganisms to the attachment to plant and animal tissue found in food is the first step toward their growth and multiplication in food (Rawat, 2015). Several pathogenic microorganisms, including *E. coli, Campylobacter, Listeria, Salmonella, Klebsiella*, and *Pseudomonas* species pose serious hazards to food especially due to their ability to form biofilms on ready to eat, and on minimally processed food (Ugwu et al., 2022; Giaouris & Simões, 2018). The formation of biofilm on the solid material by micro-organisms is a four-step process as shown in Fig. 3.1 and described below (Myszka & Czaczyk, 2011).

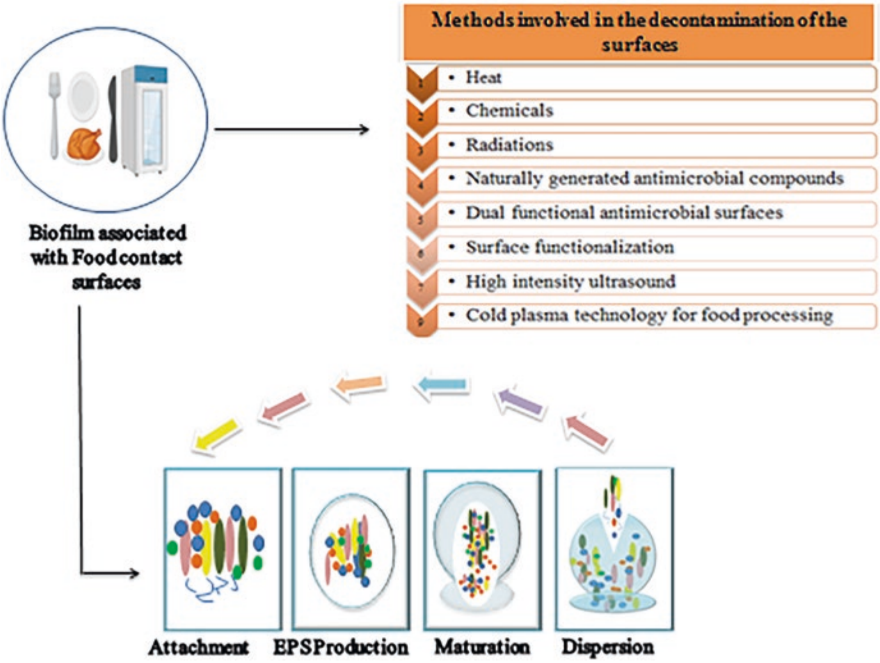

Fig. 3.1 Process of biofilm formation on the food contact surfaces and possible methods for its eradication

(i) Planktonic microorganisms can reversibly attach to solid surfaces.
(ii) The development of biofilm's architecture and the transition from reversible to irreversible adhesion induced by bacteria producing extracellular polymers (EPS).
(iii) Maturation of micro-colonies in a mature biofilm.
(iv) Dispersion of cells from biofilm into the surrounding environment.

Single cells connect to abiotic surfaces to start biofilm formation (Okshevsky & Meyer, 2015). It is possible to generally divide this time-dependent process into two phases: the reversible phase and the irreversible phase. Van der Waals and electrostatic forces cause bacteria to adhere to surfaces within a range of 2–50 nm, at the beginning of the reversible adhesion. Because the majority of bacteria are negatively charged, the negative charge on the surface will lead to electrostatic repulsion. Whereas in the irreversible phase, forces like hydrophobic, dipole-dipole, ion-ion, ion-dipole, covalent bonds, and hydrogen interactions are also involved in interaction with surfaces (Myszka & Czaczyk, 2011). The bacterial attachment to the surfaces and detachment from such surfaces is a survival strategy by the bacteria's host environment because the attachment to host surfaces is advantageous for microbes as it provides nutrients to the microbes minimizing competition for nutrients

(Abebe, 2020). But on the contrary, the microbes may also have the mechanism to evade protective measures taken by the host against such microbial attachment. In the same way, detachment may promote the movement of the bacteria to another potential host surface especially when the environmental condition becomes unfavorable. The maturation of the biofilm starts once bacteria have irreversibly bound to a surface (Berne et al., 2018). The communication between a right quorum of the bacterial population favoring a strong biofilm is facilitated by AHLs (Acylated homoserine lactones) in Gram-negative bacteria and by peptides among Gram-positive bacteria. These act as signaling molecules for cell-to-cell communication regulating population density and gene expression to control the development of biofilms and the release of cells (de Dieu Habimana et al., 2018). The nutrients used by the cells to grow and divide are obtained from the fluid environment around them. As a result, micro-colonies begin to grow and merge into layers of cells that blanket the surface. According to the cultural conditions, the biofilm takes several days to grow in terms of thickness (Moreno Osorio et al., 2021). As the biofilm ages, the associated bacteria separate and scatter in order to survive and colonize new niches. This is how the bacterial biofilm colonizes the food surfaces and causes foodborne diseases (González-Rivas et al., 2018). Various disinfectants for surfaces and modified antimicrobial surfaces are being used nowadays to protect food contact surfaces from potential pathogens. Some microorganisms like, *L. monocytogenes* form biofilms that are so strong that they cannot be removed even after cleaning with disinfectant (Galie et al., 2018).

Food Spoilage by Microbes

Food spoilage is caused by various types of yeasts, mold, and bacteria (Petruzzi et al., 2017). Yeasts are typically known for their ability to raise bread and ferment various alcoholic beverages and can grow in food with or without oxygen (Mani, 2018). They frequently colonize high-sugar or high-salt foods, pickles, sauerkraut, spoiling maple syrup, etc. (Rawat, 2015). Low-pH fruits and liquids are other targets, and some yeast can also grow on the surfaces of cheese and meat. *Candida* spp., *Cryptococcus*, *Debaromyces*, *Hansenula*, *Dekkera/Brettanomyces* spp., *Pichia*, *Phodotorula*, *Torulopsis*, *Trichosporon*, and *Zygosaccharomyces* spp., etc. are the few examples of yeasts responsible for food spoilage (Leyva Salas et al., 2017). Molds often create airborne spores, that may develop effectively on solid substrates in the presence of oxygen. Spoilage molds include species of *Aspergillus*, *Byssochlamys*, *Fusarium*, *Mucor*, *Rhizopus*, *Penicillium*, etc. (Sahu & Bala, 2017). Bacteria can grow at different temperatures and can be grouped as psychrotrophilic, mesophilic, and thermophilic (Le Marc et al., 2021). Generally, thermophilic spore-forming bacteria with the ability to tolerate high temperatures are mainly responsible for the spoilage of canned food (Petruzzi et al., 2017). Bacteria (*Campylobacter jejuni*, *Bacillus cereus*, *Clostridium botulinum*, *Clostridium perfringens*, *Cronobacter sakazakii*, *Escherichia coli*, *Listeria monocytogenes*, *Shigella* spp., *Staphylococcus aureus*, *Salmonella spp.*, *Vibrio* spp., and *Yersinia enterolitica*), viruses (*Noroviruses and Hepatitis A*) and parasites (*Toxoplasma gondii, Cyclospora cayetanensis* and *Trichinella spiralis*) are common foodborne pathogens (Bintsis, 2017). Fungi like *Diplodia*, *Monilinia*, *Alternaria*, *Phomopsis*, *Rhizopus*, *Botrytis*, *Pencillium*, *Fusarium*, etc. are the most frequent pathogens that cause rots in fruits and vegetables. *Erwinia, Pseudomonas*, and other bacteria may inflict serious damage to food (Shanmugam et al., 2021).

Foodborne Illnesses

Acute or sub-acute non-infectious diseases caused by the food containing biological agents are referred to as foodborne diseases or food poisoning (Hernández-Cortez et al., 2017). Contaminated food (by pathogens, parasites, viruses, and chemical substances) is responsible for more than 200 diseases from diarrhea to cancers (Bhaskar, 2017). Foodborne illnesses are usually infectious or toxic, many may lead to long-term disability, and death (Sharif et al., 2018). It causes diseases, malnutrition and risks food security, and increases public health concerns. Foodborne illnesses include *Staphylococcal* poisoning, *Vibrio* infection, *Mycotoxin* poisoning, *Enterohemorragic collitis*, Cholera, *Escherichia* gastroenteritis, non-hemorrhagic colitis, and salmonellosis. (Gourama, 2020). Malnutrition affects infants, young children, the elder, and the immunocompromised person (Steiber et al., 2015). The impact of foodborne infections on public health and the economy is reported to make it difficult to establish links between food contamination and consequent illness and death. According to the WHO report (2015) on the disease burden of 31 common foodborne agents at the global and sub-regional levels, it is estimated that 600 million cases people (nearly 1 in 10) worldwide get sick after eating contaminated food and 420,000 die every year. Which corresponds to the loss of 33 million healthy life years). Foodborne diseases have a different impact on different age groups. Children under the age of 5 years constitute 40% of global foodborne illnesses leading to an annual death of 125,000 (Amodio et al., 2022). In addition to burdening health care systems, foodborne infections also harm national economies, international trade, and tourism (Negesso et al., 2016). The WHO observed the prevalence of foodborne diseases in the African region. Over 92 million people get sick each year, and 137,000 die every year (Bisholo et al., 2018). Out of which 70% of foodborne illnesses in Africa result in diarrheal infections. Non-typhoidal Salmonella, which can spread through contaminated eggs and poultry and is responsible for more than half of the global deaths, killing about 32,000 people annually in the Region. *Taenia solium* (the pork tapeworm) alone causes 10% of foodborne illnesses and is a matter of concern (Eng et al., 2015) (Table 3.1).

Table 3.1 Foodborne illnesses, causal agents, symptoms, and epidemiology

Foodborne illness	Microbes involved	Symptoms	Food source	Geographic distribution	References
Bacteria					
Staphylococcal poisoning	*Staphylococcus aureus*	Nausea, vomiting, stomach cramps, and diarrhoea	Eating product contaminated with staph toxin	Most frequent foodborne illnesses worldwide	Zhang et al. (2022), Johler et al. (2015), and Lee et al. (2022)
Vibrio infection/ Vibriosis/Acute gastroenteritis	*Vibrio vulnificus*, *Vibrio cholera*	Watery diarrhoea, vomiting and abdominal pain	Raw or undercooked seafood, rice, vegetables, millet gruel	Worldwide	Dutta et al. (2021), Fung et al. (2018) and Osunla and Okoh (2017)
Enterohemorragic collitis	*E. coli O157:H7, E. coli O26:H11*	Vomiting, fever, headache, nausea, and diarrhoea	Undercooked meat, unpasteurized milk, contaminated fruit and vegetables	Worldwide	Lye et al. (2013), Adley and Ryan (2016) and Heredia and García (2018)
Escherichia gastroenteritis	Enteropathogenic and enterotoxigenic *E. coli*	Diarrhoea, stomach cramps and occasionally fever	Contaminated ground beef or water or unpasteurized milk	High risk areas include Africa, Mexico, and America	CDC (2019), Hazen et al. (2017) and Lääveri et al. (2018)
Bacterial hemorrhagic enterocolitis	*Campylobacter*, *Salmonella*, *Shigella*, enteroinvasive and enterohemorrhagic *Escherichia coli*, *Yersinia*, *Chlamydia*, *Neisseria*, and *tuberculosis*	Bloody, mucopurulent stools that are frequently accompanied by fever, tenesmus, and stomach pain	Ingestion of contaminated food and water	Worldwide	Alharbi et al. (2022), Ganguly et al. (2012) and Dejene et al. (2022)
Salmonellosis	*Salmonella*	Diarrhea, fever, and stomach cramps	Animal origin products	Coastal counties, non-coastal counties	Ame et al. (2022), Chlebicz and Śliżewska (2018) and Godínez-Oviedo et al. (2022)

Campylobacteriosis	*Campylobacter jejuni*	Dysentery or bloody diarrhoea syndrome, which typically includes cramps, fever, and pain	Raw milk, undercooked or uncooked meat, poultry, and shellfish	In Australia, campylobacteriosis is the most commonly reported foodborne infection	Epps et al. (2013), Kaakoush et al. (2015) and Lee and Yoon (2021)
Listeriosis	*Listeria monocytogenes*	The main symptoms include fever, chills, muscle pains, nausea, and diarrhea. Other consequences include miscarriage in pregnant women, infant deaths, it also effect people with compromised immune systems	*Listeria* is present in unpasteurized dairy products, a wide range of ready-to-eat foods, and can survive in refrigerator conditions	Widely distributed in the natural environment	Jackson et al. (2016), Donovan (2015) and Madjunkov et al. (2017)
Viruses					
Food poisoning/stomach flu/stomach bug/infectious gastroenteritis	*Norovirus*	Abdominal pain, watery diarrhoea, vomiting, and nausea	Consumption of shellfish, such as oysters, direct interaction with an infected individual, drinking or eating tainted food	United States	Gourama (2020), Adley and Ryan (2016) and Ushijima et al. (2014)
Liver disease	*Hepatitis A virus*	Long-lasting liver disease	Raw or undercooked seafood or contaminated raw produce, ingestion of HAV-contaminated food or water	Central and South America, the Middle East, the Indian subcontinent, and Africa	Mohammad et al. (2018), LaRocque and Harris (2021) and Switaj et al. (2015)
Gastroenteritis	*Rotaviruses*	Severe diarrhea, vomiting, fever, and dehydration	Ingestion of contaminated food such as shellfish, salads, or ice	Worldwide	Lai et al. (2020), Stuempfig and Seroy (2021) and Oteiza et al. (2022)

(continued)

Table 3.1 (continued)

Foodborne illness	Microbes involved	Symptoms	Food source	Geographic distribution	References
AstV gastroenteritis	*Astroviruses*	Watery diarrhoea	Contaminated food and water are major sources	Worldwide	Pakbin et al. (2022), Sajewski et al. (2022) and Omosigho et al. (2022)
Gastroenteritis	*Sapovirus*	Diarrheic stools tend to be watery and non-bloody	Eating of raw bivalves such as oysters	Worldwide	Sajewski et al. (2022) and De France et al. (2022)
Parasites					
Cystic echinocccosis	*Echinococcus granulosus*	CE causes harmful, slowly enlarging cysts in the liver, lungs, and other organs	Echinococcus spp., can be transmitted as contaminants of food	Argentina, Peru, East Africa, Central Asia and China	Joanny et al. (2022), Mahmood et al. (2022) and Gabriël et al. (2023)
Taeniasis	*Taenia saginata* (beef tapeworm), *Taenia solium* (pork tapeworm), and *Taenia asiatica* (Asian tapeworm)	Abdominal pain, weight loss, digestive disturbances, and possible intestinal obstruction	Eating contaminated beef or pork	*T. saginata* occur in Eastern Europe, Russia, eastern Africa and Latin America, *Taenia solium* taeniasis is seen in the United States, and *Taenia asiatica* is limited to Asia and is seen mostly in the Republic of Korea, China, Taiwan, Indonesia, and Thailand	Lianou et al. (2023), Owusu-Apenten and Vieira (2023) and Pradhan and Karanth (2023)
Toxoplasmosis	*Toxoplasma gondii*	Symptoms include muscle pain, fever and headache, all of which can last for weeks	Eating undercooked, contaminated meat (especially pork, lamb, and venison) or shellfish (for example, oysters, clams or mussels)	Toxoplasmosis is usually more prevalent, especially in moist, warm and low altitude regions	Kuruca et al. (2023), Montazeri et al. (2020) and Lianou et al. (2023)

Ascariasis	*Ascaris lumbricoides*	Abdominal discomfort or pain	By eating vegetables or fruits that have not been carefully peeled, washed, or cooked	Worldwide	Oniya et al. (2023), Sumner and Peters (2023) and Devleesschauwer et al. (2018)
Gastrointestinal amebiasis	*Entamoeba histolytica*	Diarrhea	Contaminated food	Tropical and subtropical developing countries	Pal (2020), LaRocque and Harris (2019) and Ünüvar (2018)
Prions					
Creutzfeldt-Jakob disease (vCJD)	*Prion* protein	Personality changes, memory loss, impaired thinking, blurred vision or blindness, insomnia, incoordination, difficulty speaking, difficulty swallowing	Consumption of beef products from cattle infected with bovine spongiform encephalopathy (BSE), a condition sometimes referred to as "mad cow disease"	Worldwide	Seed et al. (2018), Forsythe (2020) and Kennedy et al. (2020)
Toxins					
Mycotoxin poisoning/ Mycotoxicosis	*Aspergillus*, *Penicillium* and *Fusarium*, and others include *Alternaria*, *Claviceps* and *Stachybotrys*	Nephropathy, different cancers, alimentary toxic aleukia, hepatic illnesses, hemorrhagic syndromes, immunological and neurological conditions	Mycotoxins can be consumed directly through staple foods or indirectly through animals fed contaminated feed, particularly through milk	Worldwide	Liew and Mohd-Redzwan (2018), Awuchi et al. (2022) and Cinar and Onbaşı (2019)
Ciguatera fish poisoning (CFP)/ Ciguatoxin	*Gambierdiscus toxicus*	Nausea, vomiting, and neurologic symptoms	Consuming certain tainted tropical and subtropical fish	Indian and Pacific Ocean, and the Caribbean Sea	Friedman et al. (2017), Edwards et al. (2019) and Ikehara et al. (2017)

(continued)

Table 3.1 (continued)

Foodborne illness	Microbes involved	Symptoms	Food source	Geographic distribution	References
Paralytic shellfish poisoning/Saxitoxin	*Dinoflagellates*	Vertigo, gastrointestinal problems, and neurological issues paralysis can result in mortality and respiratory failure	Shellfish and other fish	Southern Chile, the North Sea, northwest and northeast United States, and Japan	Hurley et al. (2014), Etheridge (2010) and Ain et al. (2021)
Neurotoxic shellfish poisoning/Brevetoxin	*Dinoflagellates*	Muscle pains, ataxia, with diarrhoea, vomiting, and nausea	Shellfish and other fish	Worldwide	Sinno-Tellier et al. (2023), Abraham et al. (2021) and Estévez et al. (2023)
Puffer fish poisoning/ Tetrodotoxin	The major TTX-producing microbes belong to the genus *Aeromonas*, *Alteromonas*, *Bacillus*, *Pseudomonas*, *Shewanella* and *Vibrio*	Salivation, nausea, and vomiting are common symptoms that might lead to paralysis	Ingestion of contaminated pufferfish	East Asia, specially China and Japan	Al Dhuhaibat and Zarzour (2023), Al Homsi et al. (2022) and Anusha et al. (2021)

Source: WHO report on food safety (2022) https://www.who.int/news-room/fact-sheets/detail/food-safety

Decontamination of Food Contact Surfaces

Decontamination is the process of reducing or eradicating germs from objects, surfaces, and the environment preventing their passage and growth in food (Michels et al., 2015). Surfaces of utensils, cutting boards, flatware, tables, and highchairs which come in contact with food need to be sterilized (Menini et al., 2022). Additionally, it refers to surfaces like the microwave and refrigerator where food may spill, drain, or splash (Owusu-Apenten & Vieira, 2022). Mostly aqueous cleaning solutions are used to remove bacteria on the surface of the equipment. The food industry is using various conventional methods to sterilize equipment surfaces and machines which include heat, chemicals, and radiation (Jildeh et al., 2021). Heat in different forms like hot air, hot water, and steam reduces the number of pathogenic organisms in the food contact surfaces (Sharma et al., 2022). The application of high-velocity steam on the surface can effectively disinfect surfaces (Fukuda et al., 2020). But it only works on surfaces on which the surface is directly exposed and is not effective for concealed spaces. Radiations used for decontamination include ionizing, infrared, and UV radiation. Radiation is used less commonly than heat and chemical treatment due to the high cost (Chauhan et al., 2018). Chemicals like chlorine (reduces the biofilm of *L. monocytogenes*), chlorine dioxide (reduction of *Bacillus cereus* on stainless steel surfaces), iodine, nisin, carvacrol, hydrogen peroxide, quaternary ammonium compounds, and Triclosan (reduce the growth of *Serratia, E.coli*, and *Salmonella*), etc. (Sharma et al., 2022). Iodine and chlorine react with the food and dirt on the surfaces failing to disinfect properly. The chemical agent's temperature, contact duration, and concentration need to be carefully optimized because too high a concentration can be toxic, and too little concentration will only partially decrease harmful pathogens (Sharma et al., 2022). Other emerging technologies for the sterilization of surfaces are discussed below.

Naturally Produced Antimicrobial Compound

Various antimicrobial compounds can be used for the disinfection of surfaces but the overuse of such antimicrobials is already causing the problem of multidrug resistance. Artificial food preservatives used in food are also associated with serious health hazards (Bearth et al., 2014; Bruna et al., 2018). Hence, there is a rising need for natural products that can replace food preservatives (Castro-Rosas et al., 2017). Animals, plants, bacteria, fungi, and algae all can be used as a source of such natural antimicrobial compounds (Gyawali & Ibrahim, 2014). The effectiveness of such natural chemicals from plants has been confirmed in various studies (Sharma et al., 2022). Polyphenols obtained from grape stems inhibit the attachment of *L. monocytogenes* on stainless steel and polypropylene surfaces (Vazquez-Armenta et al., 2018). The casein protein may be effectively cross-linked by tannic acid and the films containing casein demonstrate improved physicochemical properties making it a potential film for food packaging (Picchio et al., 2018). Gallic acid (3,4,5- trihydroxy benzoic acid) has demonstrated anti-inflammatory, anti-mutagenic, antioxidant, and bacteriostatic activity (against *E. coli*, *Salmonella* spp. *S. aureus* and *C. vinaria)* (Lamarra et al., 2017). Resveratrol shows antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* (Glaser et al., 2019). Various essential oil has effective antimicrobial properties depending upon the concentration and type of essential oil used for the inhibition or eradication of pathogenic biofilm (Rossi et al., 2022). There are various essential oil studied that can inhibit the pathogens on the FCS including, carvacrol and *Helichrysum italicum* (which can inhibit the biofilm of *S. aureus*) (Bezek et al., 2022). *Thymbra capitata* a natural sanitizing solution can decrease the growth of *S. enterica* and *E. coli* (Falcó et al., 2019). *E. coli* biofilm can be reduced by 93.43% with clove oil and by 82.30% with thyme oil. *Cinnamomum cassia* and *Salvia officinalis* EOs has been shown to remove the biofilm of *S. aureus*. Cinnamon oil, marjoram oil, and thyme oil act as a disinfectant, Eucalyptus oil and cinnamon oil have antimicrobial activity against *S. aureus* and *E. coli*. Lemongrass oil inhibits the biofilm of *E. coli*. Cinnamon oil has antifungal activity against *Aspergillus niger* (Sharma et al., 2020). The chitosan film containing clove oil can be used in food packaging because of its antimicrobial activity (Saadat et al., 2022). EO obtained from *Mentha spicata* L. has anti *Vibrio* spp. activity, and can be used successfully for the preservation of food (Snoussi et al., 2015). EO from *Satureja montana* L. *Thymus vulgaris* L. has antimicrobial activity against *Salmonella typhimurium* and also helps in extending the shelf life of food (Miladi et al., 2016). Ferulic acid (Hydroxycinnamic acid) increases the quality and shelf life of freshly cut apples (Nicolau-Lapena et al., 2021).

Dual Function Antimicrobial Surfaces

The new strategies to eradicate or remove the pathogenic micro-organisms from the surfaces involve the modification of the food contact surfaces to discourage microbial attachment and build-up on food surfaces (Khelissa et al., 2017). Stainless steel and polyethylene are the most studied surfaces because of their widespread use in food processing equipment and packaging (Van Houdt & Michiels, 2010). Ideal antimicrobials should eliminate the microbes, stop them from adhering, or eradicate them if any are already present (Yu et al., 2015). Three types of dual-function antimicrobial surfaces have been developed. These surfaces include those that can kill resist, repel, and release microbes. These surfaces integrating two techniques in one system have been developed because of numerous investigations and research (Chug & Brisbois, 2022; Banerjee et al., 2011; Afewerki et al., 2020). Antimicrobial surfaces based on the combination of bactericidal and microorganism-resistant qualities are known as dual-function coatings (Zou et al., 2021). These surfaces either have a non-biofouling spacer, like a hydrophilic polymer or layer that prevents adhesion, or a significant release of an antimicrobial chemical that is contained in a non-fouling matrix (Yang et al., 2014). Ahmadi and Ahmad (2019) used the synergistic activity of -interaction and in situ graphene oxide integration to create a durable, active dual-function (antimicrobial/anticorrosive) polyurethane nanocomposite (PUC) coating. In comparison to planar aluminum, the coated surfaces demonstrated sustained anti-corrosive action in 5% NaCl solution and decreased bacterial surface colonization against *S. typhimurium* by 6.5 and *L. innocua* by 4.0 log-cycles (Sharma et al., 2022). Liu et al. (2020) created immobilized lysozyme as a super hydrophobic coating made from sintered silica nanoparticles to provide a dual-functional coating with antibacterial and anticontact capabilities for aluminum surfaces. The most cost-effective method for loading and releasing antimicrobial agents uses multiple layers as a reserve. This method is called layer by layer method (Chouirfa et al., 2019). The innovative FCS demonstrates excellent thermal insulation and ultra-lightweight characteristics (Sharma et al., 2022). Gao et al. (2019) also investigated a composite system made of a multilayer film composed of PVA/PAA and chitosan/heparin. Additionally, the controlled release of anti-microbial substances from the surface limits the colonization of microorganisms and prevents their spread (Kumar et al., 2021).

Surface Functionalization

Various techniques for surface modifications have been developed to improve the inertness and safety of the food contact materials. Different polar groups can be added to the surface using wet solvents, UV light, and adhesion (Fabbri & Messori, 2017; Nady et al., 2011). As a result, these techniques must alter the surface to incorporate a specific functional group. For surface modification. The choice of polymer is based on criteria like elasticity, conductivity, strength, kind of material (synthetic or natural), and degradability (Nemani et al., 2018). Depending on the use of the surface, the immobilization of biomolecules or functionalization of surfaces is taken into consideration (Stewart et al., 2019). To add the necessary amount and variety of the reactive functional group, the surface's functionalization processes must be improved in the second stage.

High-intensity Ultrasound

In recent years, the use of ultrasound in the food business has attracted a lot of attention (Gallo et al., 2018). Ultrasound is regarded as an economical technique in the food industry (Mason et al., 2011). High-intensity, high-frequency sound waves propagating through liquid are used to speed up the cleaning of surfaces submerged in ultrasonically activated liquid (Chemat & Khan, 2011). Ultrasound has is becoming increasingly popular in recent times and has a wide range of uses in chemical reactions and surface conditioning (Azam et al., 2020). Numerous advantages of this non-destructive technique include reliable cleaning, microbiological safety, and assurance of food quality (Bhargava et al., 2021). But more investigations are needed to make the technology affordable for industrial applications. The technology of ultrasonic cleaning is distinct and incredibly effective as it can penetrate and clean any surface using sound-conducting liquid as the medium (Gallo et al., 2018). It is also capable of cleaning complicated chores like tread roots, tiny surface shapes, blind holes, and others (Mason, 2016). A positive pressure during the compression cycle can force molecules closer together, whereas a significant negative pressure during the expansion cycle can overcome the liquid's tensile strength and cause gaps. The surfaces created via ultrasonography have a porous shape, a large surface area, and good stability. Because of its antibacterial and self-cleaning qualities, the porous matrix can be filled with antimicrobial materials, covered in various types of coatings, and used as a multifunctional surface (Kollath & Andreeva, 2017).

Cold Plasma Technology for Food Processing

Irving Langmuir coined the name "plasma" in 1928 to describe the fourth state of matter, which is an entirely or partially ionized state of the gas. It is widely used in textiles, electronics, life sciences, and food packaging. (Pankaj et al., 2014; Ekezie et al., 2017; Misra et al., 2019). In the past, plasma technology is utilized as a surface-cleaning tool (Thirumdas et al., 2015). It has been used commercially as disinfection agents on medical equipment surfaces made up of heat-sensitive polymers. For its unique benefits, such as zero or minimal influence on substrate materials, plasma technology is employed in the biomedical sector for the cold sterilization of tools and prostheses as well as for various temperature labile materials (Trimukhe et al., 2017; Desmet et al., 2009). Ionization is consistently regarded as the most crucial element in the processing of plasma, followed by other elements such as reaction rate, rate constants, the mean free path, and the electron energy distribution (Thirumdas et al., 2015). Based on reactions, the plasma chemical process can be split into two groups. There are two types of reactions: homogeneous gas-phase reactions (such as the creation of N_3 from N_2) and heterogeneous reactions, in which plasma interacts with a solid or liquid medium (Tiwari et al., 2020). Plasma can be produced by exposing a gas to an electric field, either continuously (direct current field) or at alternating time interval (typically high-frequency field). These energy sources raise the electrons' kinetic energy, which increases the number of collisions in the gas and causes the generation of plasma products including electrons, ions, radicals, and radiation of various wavelengths, including UV radiation (Bogaerts & Neyts, 2018). According to a report, plasma can penetrate 10 μm deep, but UV rays can only reach a depth of 1 μm. This makes plasma useful for killing and inactivating spore forming bacteria (Jaiswal & Sinha, 2015). O_2 plasma demonstrated effective biocidal action on *B. subtilis* and *Clostridium sporogenes*. Plasmas produced at 200 W were sufficient to kill more than 3.5 $\log_{10}$ of *B. subtilis* in 5 min (Moisan et al., 2001). Hence, cold plasma technology can be effectively used for killing microbes on fresh products to increase shelf life (Bagheri & Abbaszadeh, 2020). In a recent study, it was found that strawberries treated with cold plasma had a 12–85% decrease in the total mesophilic count and a 44–95% decrease in the yeast and mold counts (Misra et al., 2014). Gurol et al., (2012), used low-temperature plasma to treat raw milk to kill *E. coli*. It was observed that applying cold plasma technology against food pathogens (*L. monocytogenes* and *S. typhimurium*) can reduce their growth (Katsigiannis et al., 2021). Various microbes are inactivated by the cold plasma including *E. coli*, *S. typhimurium*, *L. monocytogens*, *A. paraciticus*, *G. liquefaciens*, *A. flavus*, *A. hydrophila*, *C. albicans*, *S. cerevisiae*, *P. agglomerans*, and *S. enteritidis* (Mandal et al., 2018; Birania et al., 2022). Cold plasma technology is very useful in food packaging as it runs all over the surface and successfully helps to sterilize the outer surface during the handling, transportation, and distribution of packaged food (Ekezie et al., 2017; Pankaj et al., 2014; Misra et al., 2019; Roobab et al., 2022). Cold plasma technology modifies the surfaces by adhesive bonding, cleaning, coating, painting, and printing. Cold plasma can be used to sterilize heat-sensitive packing materials like polycarbonate and polythene because of its low temperature.

Public Health Concern

Bio-deterioration is seen as a significant concern for the food business which can be described as any unfavorable alteration in the food by microbes. Which results in a loss in its nutrient content, and change in colour, or texture making food more brittle. Managing microbiological food safety requires a multifaceted approach and addressing the questions of how to establish effective controls without adding to the cost or compromising flavor and nutritional value. The entire food supply chain must be thoroughly studied for effective management of microbial risk. Screening the microbiological load in the finished product typically fails in terms of hazard control because it is impossible to test enough samples to find pollutants at levels that reflect unacceptable health concerns. Pathogenic bacteria (*L. monocytogenes*, *S. aureus*, *E. coli*) present in raw materials such as, fish, raw meats, and poultry may spread to other food items, such as cooked or raw foods, during food storage or preparation. Additionally, food products may become contaminated during food processing. A particular bacterial strain, temperature, pH, nutrient content, type of contact surfaces, and quality of contact surfaces are a few of the variables that might affect the formation and distribution of the biofilm. An effective approach is required, starting with the manufacturer guaranteeing a secure procedure and product design and anticipating potential issues. Fruit and vegetables are the important raw food consumed all over the world. Following China, India is the second-largest producer of fruits and vegetables. However, due to the losses in the field and during storage, their supply becomes insufficient. Roughly 30% of fruits and vegetables are spoiled after being harvested and become unfit for human consumption. According to estimates, soft rot caused by bacteria is responsible for 36% of vegetable degradation. Therefore, it is essential to implement appropriate measures for the safety of food.

Conclusions and Future Recommendations

Microbes that cause spoilage incur enormous losses in agricultural and food production impacting the national budget and pose threat to food security. To decrease the prevalence of foodborne infections, it is crucial for developing country governments, politicians, researchers, and the general public to work together. In poor nations, the use of quick procedures for detecting foodborne pathogens is necessary. To reduce harmful health impacts, proper safety measures must be taken during cooking and maintaining personal hygiene. Research must advance in the field of biofilm study methodologies to better comprehend and manage biofilms in food processing facilities. Getting rid of dead bacteria from food contact materials and preventing the initial microbial adhesion are challenges for the food business because the pathogenic bacterial biofilms are responsible for the spread of foodborne illnesses. Several emerging technologies have been identified as having the potential to increase the efficacy of materials used in food contact surfaces by reducing microbial contamination. Surface functionalization, high-intensity ultrasound, and cold plasma are surface decontamination approaches that are used to completely eradicate pathogens from food contact surfaces.

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