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Foodborne Pathogens: *Staphylococcus aureus* and *Listeria monocytogenes* An Unsolved Problem of the Food Industry

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Abstract: Foodborne illness is a serious threat to public health around the world. Foodborne illness is caused by the consumption of harmful bacteria in form of contaminated food. The contamination of food occurred throughout the food chain from farm to industry and from market to kitchen. During the last few decades, the number of outbreaks caused by foodborne pathogens has dramatically increased. Consumers are now demanding fresh and safe food products. Food industry has shown deep concern about the safety of foods and in response adopted a number of decontamination techniques to ensure safe food supply. Among 31 foodborne pathogens, the most common pathogens found in the foods are *Staphylococcus aureus* and *Listeria monocytogenes*. These pathogens have been contributing significantly to the foodborne outbreaks and deaths toll around the world. Control of these pathogens became a great challenge for the food industry. This review focuses on various decontamination technologies used in the food industry to ensure food safety and to prevent these pathogens in the food products.

Key words: Foodborne illness, food industry, food safety, foodborne pathogens, decontamination techniques

INTRODUCTION

According to the Center of Disease Control and Prevention (CDC), there are 31 known foodborne pathogens which cause infections in humans. All the people are susceptible to the infection, but few are at great risk for developing foodborne illness. An estimated illness of 48 million with 0.128 million hospitalization and 1.351 thousands of death reported annually in United Sates alone (CDC, 2015a, Rahman *et al.*, 2012). The wide array of foodborne pathogens includes a variety of aerobes and anaerobes, enteric bacteria, viral pathogens, parasites, marine dinoflagellates and self-inducing prions of the transmissible encephalopathies (Table 1). These broad varieties of foodborne pathogens are likely to cause a wide array of illnesses in the human host, mostly with a gastrointestinal component of vomiting or diarrhea. There are other "invasive ones" that produces other clinical syndromes, and the foodborne toxins can perturb almost any biological system of the body. So practically the phrase "foodborne disease" covers many pathogens and many diseases (Tauxe, 2002).

Foodborne illness is generally thought to be a slight self-limiting gastrointestinal illness; however it may reach to a much severe conditions sporadically. Bacterial foodborne illness is divided into two general categories i.e. (A) gastrointestinal infections, that results from proliferation of pathogenic microorganisms in infected hosts like salmonellosis and, (B) bacterial toxin release in the body of infected host due to bacterial growth that is manifested as food poisoning for instance in case of *Bacillus cereus* in food (Abubakar *et al.*, 2007). Diarrhea is one of the most symbolic and distinguishing sign of bacterial foodborne illness and it results due to discrepancy of secretion and absorption of ions and solutes across the gut's epithelia (Viswanathan *et al.*, 2009). While other etiological characteristics of bacterial induced food poisoning includes abdominal pain, acute diarrhea, vomiting and stomach cramps in illness caused by *B. cereus*, malaise and pro dermal fever caused by *Campylobacters*, dizziness, lassitude, fatigue and CNS disturbances initiated by *Clostridium botulism*, diarrhea, abdominal pain, nausea, and rare vomiting by *Clostridium perfringens* and gastrointestinal symptoms, septicaemia, meningitis, abortion in pregnant females, and some flue like symptoms are caused by *Listeria monocytogenes* (Roberts and Greenwood, 2003).

Recently, *Vibrio cholerae*, *Salmonella enterica*, *Listeria monocytogenes*, *Escherichia coli* O157:H7, *Cryptosporidium parvum,* Campylobacter spp. and other

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Table 1: List of foodborne pathogens found in various food products (CDC, 2015a)

Foodborne pathogens	Mainly found
Norovirus	Leafy vegetables, RTE foods, fruits and mollusks, contaminated personnel's hand
Astrovirus	Contaminated food and water, contaminated personnel's hand
Hepatitis A virus	Vegetables, water, fruits, feces and personnel's hand, raw or undercooked shellfish, undercooked foods
Rotavirus	Feces, contaminated food and water, contaminated personnel's hand, respiratory droplets
Sapovirus	Feces, contaminated food and water, contaminated personnel's hand,
Trichinella spp.	Raw or undercook meat, pork horsemeat or wild carnivores such as fox, cat or bear
Toxoplasma gondii	Raw or undercooked meat, contaminated surfaces and water, feces, organ transplant or blood transfusion from infected person
Cyclospora cayetanensis	Fecally contaminated food or water, vegetables and fruits
Cryptosporidium parvum	Feces, contaminated food or water, fruits and vegetables, farm animals
Giardia lamblia	Surfaces or in soil, food or water contaminated with feces
Brucella	Contaminated food, unpasteurized milk and cheese, infected animals, aerosols or dust
Bacillus cereus	Various food especially rice, leftovers, sauces, soups and RTE foods
Campylobacter	Raw and undercooked poultry, contaminated water, unpasteurized milk
Clostridium botulinum, foodborne	Home-canned vegetables, honey, fruits, corn syrup, fish, herb-infused oils, potatoes, cheese sauce, bottled garlic
Clostridium perfringens	Mainly found in beef, poultry and gravies
E. coli (STEC) O157	Contaminated water, undercooked beef, unpasteurized milk, raw fruits and vegetables, animals, feces
E. coli (STEC) non–O157	Contaminated water, undercooked beef, unpasteurized milk, raw fruits and vegetables, animals, feces
Enterotoxigenic *E. coli* (ETEC)	Contaminated water, undercooked beef, unpasteurized milk, raw fruits and vegetables, animals, feces
Diarrheagenic *E. coli* other than STEC and ETEC	Contaminated water, undercooked beef, unpasteurized milk, raw fruits and vegetables, animals, feces
Listeria monocytogenes	RTE foods, pates and meat spreads, unpasteurized milk and cheese, smoked foods, raw sprouts
Mycobacterium bovis	Eggs, meat and poultry, unpasteurized milk or juice and cheese, raw fruits, alfalfa sprouts, melons, spices, nuts
Salmonella spp., nontyphoidal	Eggs, meat and poultry, unpasteurized milk or juice and cheese, raw fruits, alfalfa sprouts, melons, spices, nuts
S. enterica serotype Typhi	Eggs, meat and poultry, unpasteurized milk or juice and cheese, raw fruits, alfalfa sprouts, melons, spices, nuts, animals
Shigella spp.	Food, water, infected persons, salads and sandwiches, raw vegetables
Streptococcus spp. group A	Milk and their products, egg, meat and pork and their products, rice, shrimps salad, personnel's hands
Staphylococcus	Ham, egg, potato, macaroni, tuna, chicken, confectionaries, sandwiches, milk and their products, eggs, meat and poultry
Vibrio (non-cholera)	Raw or undercooked shellfish, especially water where oysters are cultivated
V. cholerae, toxigenic	Raw or undercooked shellfish, oysters containing water
V. vulnificus	Raw or undercooked seafood, especially water where oysters are cultivated
V. parahaemolyticus	Raw or undercooked shellfish, water where oysters are cultivated
Yersinia enterocolitica	Feces, water, food, wild or domestic animals particularly pigs, milk and their products, raw pork and pork products, shellfish

multi-drug resistant microbial entities have been described as emerging infectious agents that are likely to cause a newly appeared infection in a population with an increased incidence (Lukinmaa, 2003). However, in terms of disease burden in many countries, *C. perfringens, Campylobacter spp*, *Salmonella*s, EHEC O157 and *L. Monocytogenes* followed by *S. aureus* represents the major bacterial pathogens and healthcare issue (Todd, 1996).

In the last few years, the surveillance and its related technology for the food related infections has improved several folds which has resulted in effective monitoring and now more number of infections and outbreaks are being reported (Scallan *et al.,* 2011a). Moreover, many of these outbreaks are linked with an increasing number of foodstuffs, ranging from waffles to cookie dough; as a result more companies are being affected. Food industry has flourished with these improvements bringing health to human race. Potential outbreaks of foodborne diseases can have a serious impact on the health of consumers but may lead to an economic outcry. Consumer confidence which is integral part of food industry can fade as a consequence to an outbreak related (Hussain, 2013).

The aim of the current study is to discuss foodborne pathogens and possible threats to food industry in general. In particular, this review will focus on the *S. aureus* and *L. Monocytogenes* importance, outbreaks and their control in foods using intervention technologies to ensure food safety.

***S. aureus* as foodborne pathogen**: *S. aureus* is a Gram-positive, anaerobic facultative, catalase and coagulase-positive microorganism. It can be found as part of the microbiota of human beings and animals (Loir *et al.,* 2003) It is an important pathogen because of their antibiotic resistance, toxin-mediated virulence, ubiquitous nature, and invasiveness. *S. aureus* is capable of reproducing in a wide range of physical conditions of temperature, pH and salt concentration (Chaibenjawong and Foster, 2011). *S. aureus* is capable to survive in dry and stressful conditions, such as human skin, nose and also found on non-living surfaces such as clothing, gloves, and food contact surfaces (Kadariya *et al.,* 2014). *S. aureus* can be found in a variety of foods because of its ability to reside broad array of spaces in close proximity of human beings (Loir *et al.,* 2003; Tang *et al.*, 2016).

Moreover, *S. aureus* is a leading cause of foodborne illness worldwide, causing an estimated 2.41 million illnesses per year in the United States alone (Scallan *et al.,* 2011b). The basic cause of all these reported illness is by consuming food contaminated with *S. aureus* derived toxins. About 1,000 patients are hospitalized based on the severity of infection; 6 deaths may happen each year (Scallan *et al.,* 2011b). Severity of symptoms depends on the amount of toxin consumed (Safety, 2015). Disease condition is caused when the concentration of toxin in the body increased from 10^5 CFU/ml. Previous reports showed that a small amount of toxins (~0.5 ng/ml) present in chocolate milk caused a large outbreak (Evenson *et al.,* 1988). Disease symptoms generally appear in 1-6 hours after eating the contaminated food. This is due to the production of toxins by the *S. aureus* during growth at suitable temperatures. The signs of disease are generally minor and maximum people get well within 1-3 days depends on the amount of toxin ingested (Le Loir *et al.,* 2003).

Staphylococcal enterotoxins (SEs) consist of 21SE types (ranges from sea to selv). They are heat stable and belong to the large family of pyrogenic toxin superantigens (Kadariya *et al.,* 2014). Although the toxic shock syndrome toxin-1 (TSST-1) shows various biological properties of SEs, but no emetic activity. However, TSST-1 can inducer massive proliferation of T-cells and production of cytokines which causes a lethal shock and multisystem failure (Johler *et al.,* 2013). SEs has superantigenic activity such as immunosuppression and nonspecific T-cell proliferation (Fig. 1).

These toxins are highly stable, resistant to environmental conditions like drying, freezing as well as remarkable heat-resistant (Argudín *et al.,* 2010; Hennekinne *et al.,* 2012). They are unaffected by low pH, proteolytic enzymes like pepsin or trypsin which allows an easy, unperturbed stay in the gastrointestinal tract making them functional throughout the gastrointestinal tract (Kadariya *et al.,* 2014; Dinges *et al.,* 2000). These characteristic features of *S. aureus* and its toxin make it as a significant threat in food industry. The exact mechanisms by which these toxins poison the food are not well understood. However, it is believed that SEs stimulates the vagus nerve system at the intestinal epithelium that transmitted signals to the emetic center of the brain (Kadariya *et al.,* 2014; Argudín *et al.,* 2010). Research showed that SEA toxin is the most common toxin reported in various outbreaks. About 1300 cases results from SEs in Australia per year (Fletcher *et al.,* 2015). In addition, 77.8% SEA toxin was found in Staphylococcal foodborne diseases outbreaks in United States followed by SED (37.5%) and SEB (10%) (Argudín *et al.,* 2010; Balaban and Rasooly, 2000). Staphylococcal food poisoning is mostly linked to SEC and SEE. SEC was responsible for the contaminated coleslaw which caused an outbreak in the United States produced by methicillin-resistant *S. aureus* (MRSA) (Jones *et al.,* 2002). In 1980, SEC also resulted in outbreaks in Canada (De Buyser *et al.,* 2001) while 2001-2003 and 2009 in Taiwan and Japan respectively (Chiang *et al.,* 2008; Kitamoto *et al.,* 2009).

The incidence of enterotoxin SEA has been reported in many countries worldwide. In 359 outbreaks in the

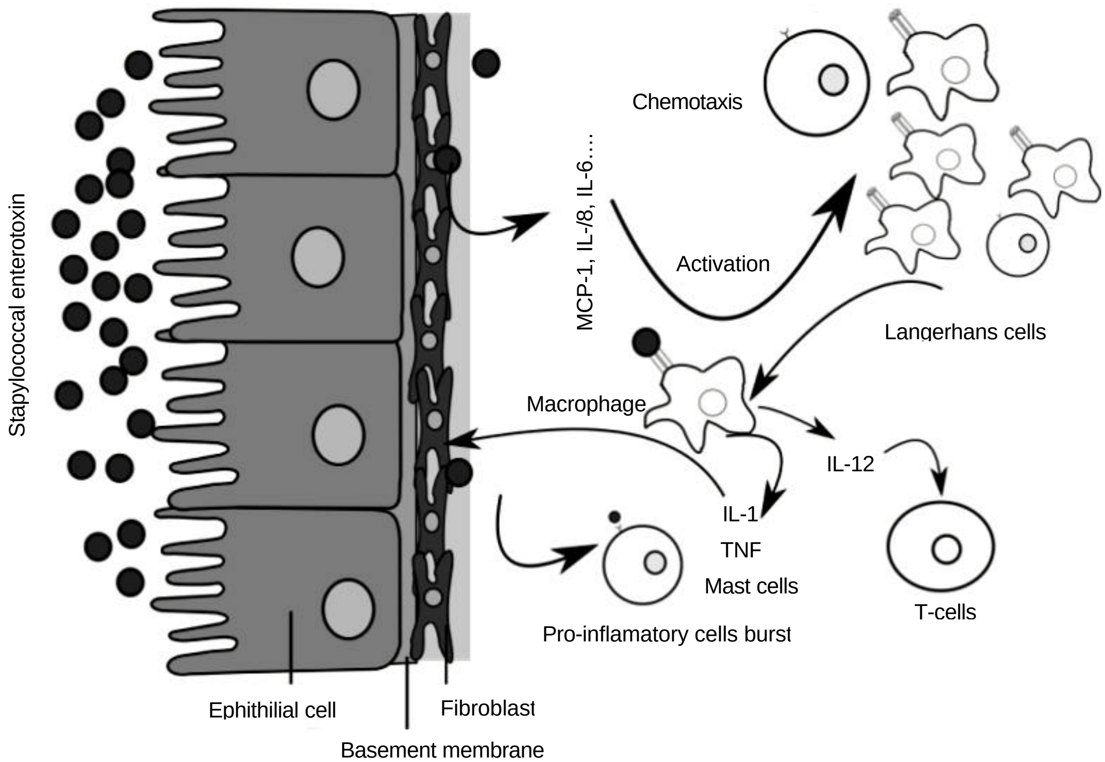

Fig. 1: SEs superantigens in gastrointestinal tract and immune response. SEs initially interacts with MHC class II including macrophage and dendritic cells, myofibroblasts and TCR expressing CD4+ T cells. After passing through epithelial cells, SEs binds with MHC class II molecules associated on myofibroblast. Chemokines and cytokines (IL-8, IL-6 and Monocyte Chemoattractant Protein-1) are produce. MCP-1 causes an increased in chemotaxis of CD4+ T cells, macrophages and dendritic, eosinophil and mast cells from gut associated lymphoid tissue towards damage area. As a result, a hyperactivation of the antigens presenting cells and T cells occur. This situation leads to high proliferation of T cells which in turn cause uncontrolled burst of proinflammatory chemokines and cytokines resulting superantigen-mediated acute inflammation and shock. Modified from (Balaban and Rasooly, 2000).

period of 1969-1990, 79% were caused by *S. aureus* strains produced SEA in foods (Wieneke *et al.,* 1993). Consumption of contaminated food (meat and poultry) including chicken and ham caused 75% of cases while SEA was found in 59.6% cases. Few cases were reported of SEA in comparison with SEC (2.5%), SEB (3.4%) and SED (15.4%). SEA was found to be linked with 31 staphylococcal outbreaks in France (69.7%). The common vehicles in those outbreaks were a variety of meat products, dairy products and salad, between 1981 and 2002 (Kérouanton *et al.,* 2007). In Australia, 40 children were affected as a result of an outbreak in 2007 which was a result of SEA and SED which was transmitted through bovine milk. The milk was intoxicated from cow (Schmid *et al.,* 2009). An outbreak in 2012 was reported of Staphylococcal food poisoning from military unit launch party in US. This outbreak affected 22 persons and the vehicle were chicken, sausage and rice dish known as perlo (CDC, 2015b). In recent report of CDC, a total of 19 outbreaks were recorded in 2014 in US, with 577 illnesses and 10 hospitalizations (Fig. 2) (CDC, 2015a). In 2015, two outbreaks so far reported in US. In these outbreaks a total of 146 illnesses were reported. The vehicle of infection was soup, bologna, apples and chicken in these infections (Http://www.Outbreakdatabase.Com., 2015).

Listeria monocytogenes as foodborne pathogen: *Listeria monocytogenes* is a well-known foodborne pathogen. *L. Monocytogenes* was first described by Murry *et al.* (1926), who coined the name *Bacterium monocytogenes* because of the character of monocytosis found in infected laboratory rabbits and guinea pigs. It was renamed later as *Listerella hepatolytica* by Pirie in 1927, who also has given its present name 1940 (Gray and Killinger, 1966). The first confirmed isolations of the bacterium from infected

Table 2: Effectiveness of decontamination techniques against *S. aureus* in different food products

Agent/technology used	Procedure*	Time	Reduction (log CFU)	Temperature (°C)	Suspension/food product	References
Electrolyzed water	SAEW, ACC 80 ppm, pH 5.6 and ORP 912 mV	2.5	ND*	23	Suspension	Ni *et al.* (2015)
	StAEW, ACC 50.3 ppm, pH 2.6 and ORP 1139 mV	1	5.9	20	Suspension	Issa-Zacharia *et al.* (2010)
	StAEW, ACC 23.7 ppm, pH 5.6 and ORP 940 mV	2	5.9	20	Suspension	Issa-Zacharia *et al.* (2010)
	StAEW, ACC 50 ppm, pH 2.6 and ORP 1100 mV	1	3.7 g	35	Lettuce	Rahman *et al.*,(2010a)
	LcEW, ACC 5 ppm, pH 6.3 and ORP 500 mV	1	3.9 g	35	Lettuce	Rahman *et al.* (2010a)
	NEW, ACC 50 ppm, pH 6.5 and ORP 800-900 mV	10	2.7 mL	25	Spinach	29
	NEW, ACC 50 ppm, pH 6.5 and ORP 800-900 mV	10	3.4 mL	25	Spinach	Guentzel *et al.* (2008)
Pulsed electric field	Electric field strength 40 kV/cm for 89 µs	-	5.2 mL	32.5	Milk	Cregenzán-Alberti *et al.* (2015)
	Electric field strength 25 kV/cm for 200 µs	-	2.1 mL	25	Milk	Zhao *et al.* (2013)
	Electric field strength 40 kV/cm for 15 µs	-	3 mL	15	Liquid whole egg	Monfort *et al.* (2010)
	Electric field strength 35 kV/cm for 500 µs	-	6.1 mL	<35	Suspension	Saldaña *et al.* (2010)
Pasteurization	Thermal treatment 62.5°C	10 min	>7 mL	62.5	Suspension	Viazis *et al.* (2008)
	Thermal treatment at 65°C	30 min	ND	65	Milk	Raimundo *et al.* (2013)
	Thermal treatment at 63°C	30	ND	63	Raw milk	Yao *et al.* (2013)
High pressure processing	400 MPa	30 min	6 mL	22	Human milk	Viazis *et al.* (2008)
	500 MPa	15 min	ND	20	Suspension	Fioretto *et al.* (2005)
	600 MPa	20	ND	20	Cheddar cheese slurry	O'Reilly *et al.* (2000)
	500	5	0.45	10	Raw milk cheese	Arqués *et al.* (2005)
	500	10	6	5	Washed curd	López-Pedemonte *et al.* (2007)
	500	5	7	50	Mato	Capellas *et al.* (2000)
Ohmic heating	15.26 V/cm, 0 sec holding time	92 sec	ND	75	Meatballs	Sengun *et al.* (2014)
	50 Hz	5 min	ND	81	Meatballs	Mitelut *et al.* (2011)

*EOW: Electrolyzed oxidizing water, LcEW: Low concentrated electrolyzed water, NEW: Neutral electrolyzed water, StAEW: Strong acidic electrolyzed water, ORP: Oxidation reduction potential, ACC: Available chlorine concentration, ND: Not detected

Table 3: *L. Monocytogenes* control in different foods using decontamination technologies

Agent/technology	Procedure*	Time (min)	Reduction (log CFU)	Temperature (°C)	Suspension/food product	References
Ohmic heating	Range of 25-40 V/cm	0.5-1.5	>5 mL	22	Orange and tomato juice	Lee *et al.* (2012)
	Range of 10-20 V/cm	1.5-2	>5 mL	22	Orange and tomato juice	Sagong *et al.* (2011)
Electrolyzed water	EOW, ORP 1183 mV, ACC 63 ppm and pH 2.4	1	7.4 mL	22	Suspension	Pangloli and Hung (2013)
	StAEW, ORP 1150 mV, ACC 20 ppm and pH 3.1	2	ND*	20	Suspension	Ovissipour *et al.* (2015)
	WAEW, ORP 950 mV, ACC 10 ppm and pH 3.5	2	ND	20	Suspension	Ovissipour *et al.* (2015)
	StAIEW, ORP -840 mV and pH 11.1	2	1.9 mL	20	Suspension	Ovissipour *et al.* (2015)
	WAIEW, ORP -715 mV and pH 10.4	2	1.9 mL	20	Suspension	Ovissipour *et al.* (2015)
	StAEW, ORP 1130 mV, ACC 50.2 ppm and pH 2.5	5	1.8 g	23	Pork	Rahman *et al.* (2013)
	EOW, ACC 38ppm and pH 2.3	10	1.1 g	22	Chicken	Al-Holy and Rasco (2015)
	EOW, ACC 38 ppm and pH 2.3	10	1.2 g	22	Trout fish	Al-Holy and Rasco (2015)
Pulsed electric field	Frequency 1700Hz, pulses 1.5 µs, flow rate 7ml/sec	-	>4 mL	50	Milk	Reina *et al.* (1998)
	25 kV/cm, pulses width 800 µs, frequency 1Hz, pH 3.8	-	5.09 mL	35	Suspension	Álvarez *et al.* (2002)
High pressure processing	400 MPa, 0.01 µs	-	1.1-3 mL	25	Suspension	Dutilly (2011)
	345 MPa	10	3.05	25	Suspension	Alpas *et al.* (2000)
	600 MPa	2	3.3	20	Cooked chicken	Patterson *et al.* (2011)
	400 MPa, pH 4.32	0.4	4 g	18	RTE salad	Marcos *et al.* (2008)
Ozonation	33 mg/min	9	6.3/25 g	NA	Chicken (25g)	Muthukumar and Muthuchamy (2013)
	5ppm	5	0.94 g	22	Lettuce	Yuk *et al.* (2006)
	0.098 mg/min/ml	5-9	5 mL	22	Orange juice	Patil *et al.* (2010)

*EOW: Electrolyzed oxidizing water, StAIEW: Strong acidic alkaline electrolyzed water, WAIEW: Weak alkaline electrolyzed water, WAEW: Weak acidic electrolyzed water, StAEW: Strong acidic electrolyzed water, ORP: Oxidation reduction potential, ACC: Available chlorine concentration, ND: Not detected, RTE: Ready to eat

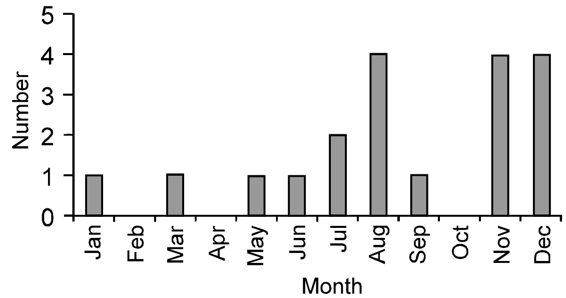

Fig. 2: Staphylococcal outbreaks in 2014 (CDC, 2015A)

individuals, following its initial description, were made in 1929 by Gill from sheep and by Nyfeldt from humans (Gray and Killinger, 1966). Since then, sporadic cases of listeriosis have been reported, often in workers in contact with diseased animals (Cain and McCann, 1986; Farber and Peterkin, 1991).

Listeria monocytogenes (Gram-positive) is a facultative intracellular pathogen responsible for listeriosis which is a rare but a severe infection of human beings (and also animals) with a mortality rate of 20-30% (Allerberger and Wagner, 2010; Swaminathan and Gerner-Smidt, 2007). Listeriosis is caused mainly by consuming the contaminated food. First evidence emerged in 1980, that food can be responsible for listeriosis outbreaks (Fleming *et al.,* 1985; Schlech III *et al.,* 1983). Since then *L. Monocytogenes* has now became an important foodborne pathogen as well as a model system for infection biology (Cossart, 2011; Hamon *et al.,* 2006). *L. Monocytogenes* can survive in diverse habitats like soil, silage, marine and fresh water, sewage, vegetation, food processing plants, food, domestic and wild animals as well as humans (Ivanek *et al.,* 2006; Sauders and Wiedmann, 2007). *L. Monocytogenes* is capable to resist environmental stresses, which otherwise limits the bacterial growth, such as heavy metal ions, high salt concentration, low pH values, low temperatures, and low water activity which enables it to successfully colonizes food processing environments.

According to the Food Standards Agency (FSA) *L. Monocytogenes* is identified as highest ranked foodborne pathogen that causes deaths in England and Wales and unlike most other common foodborne infections, the mortality rates of listeriosis was found out to be 20-30% (Todd, 1996; Adak *et al.,* 2002; FSA, 2015) which demands epidemiological scrutiny and research as a prerequisite.

L. Monocytogenes causes both invasive and non-invasive infections. Being protruding and invasive, it tends to cross the intestinal mucosal walls, reaching up to the underlying tissues and consequently within the cytoplasm of host's cell, it infects, propagates and spread to the neighboring cells without an extracellular space coverage therefore giving a run around to the immune defenses (Fig. 3) (Lukinmaa, 2003).

Invasive listeriosis is relatively rare but a severe disease and principally shows an association with a definite risk group of people and the fatality proportion is high, conversely a fairly trivial non-invasive infections can also occur in healthy people (Crum, 2002).

Several foods showed good suitability for *L. Monocytogenes* spreading (Table 1). However, foods such as processed unpasteurized milk, meats, and soft cheeses are the primary route of transmission of *L. Monocytogenes* (Asahata *et al.,* 2015). Globally it represents the 3rd leading cause of mortalities due to food poisoning. The incidence of listeria outbreaks is highly related to food and its type. RTE seafood of Japan, including sashimi and sushi are readily consumed in Japan. Examination of RTE seafood revealed that raw minced tuna (appetizer) and fish roe products are frequently found infected with *L. Monocytogenes* (5.7% to 12.1% of the time) (Miya *et al.,* 2010). Although United States Food and Drug Administration (USFDA) has established preventive regulatory guidelines for raw seafood, such as RTE foods (processed delicatessen meats, meat spreads, soft cheeses, cooked cold chicken, smoked seafood, and pre-prepared salads), that can support *L. Monocytogenes* growth (FDA, 2008), and these guidelines have been found effective to curtail *L. Monocytogenes* infections (Tappero *et al.,* 1995).

Centers for Disease Control & Prevention estimates around 1600 illness and 60 deaths due to listeriosis occur per year in the US (Scallan *et al.,* 2011b). High prevalence rates of *L. Monocytogenes* are found in Western Europe and North America than Japan. It was estimated that the incidence of *L. Monocytogenes* infection were 0.65 cases per 1 million individuals as compared to the US and Europe where 2.9 and 6.3 cases per 1 million individuals in 2006 (Asahata *et al.,* 2015). On average annual occurrence of listeriosis in US was 0.26 cases/100,000 individuals in 2013 (Crim *et al.,* 2014). When compared with the prevalence rates between 1996-98, 42% decline was observed by 2012 but however, there was no observed change in incidence of listeriosis in 2012 compared to 2006-2008 (Fretz *et al.,* 2010).

Listeriosis is rare but possess high mortality rate as compared to the other foodborne pathogens. Close examination of several outbreaks of listeriosis identifies the serotype 4b being responsible in most of the outbreaks while 1/2a serotypes has caused sporadic cases (Swaminathan *et al.,* 2001; Gerner-Smidt *et al.,* 1995). In 2012, there were 4 confirmed outbreaks in US was observed. The largest listeriosis outbreak in US history occurred in 2011, which resulted in 147 illnesses, 33 deaths, and 1 miscarriage occurred among residents of 28 states; the outbreak was linked with the consumption of cantaloupe which was brought

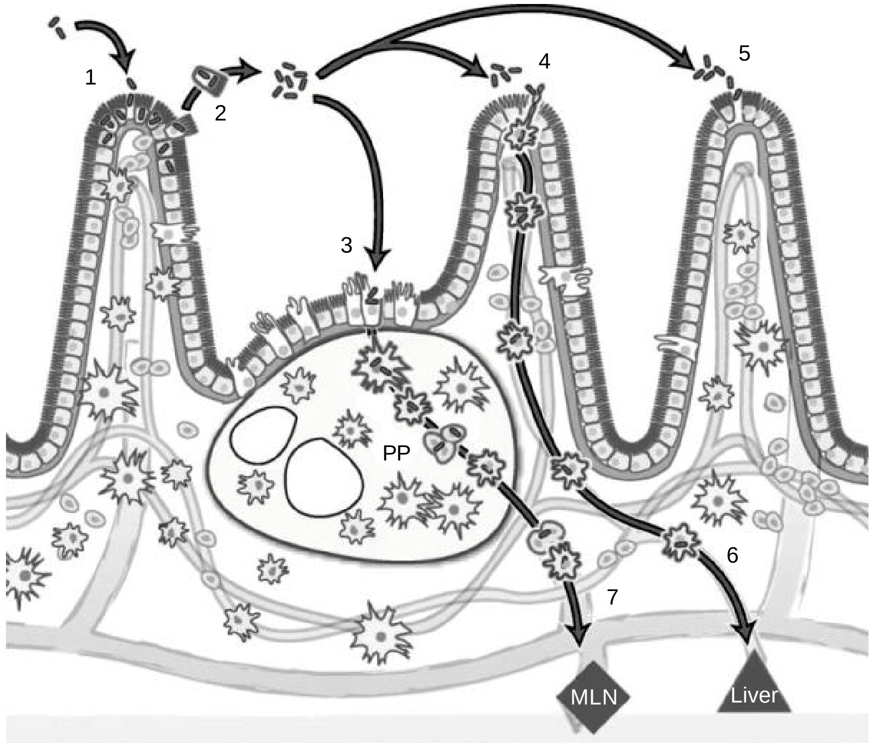

Fig. 3: Proposed model of *L. Monocytogenes* spreading from intestine to mesenteric lymph nodes (MLN) and liver. (1) *L. Monocytogenes* invades enterocyte the intestinal villi. After internalization, *L. Monocytogenes* starts replication and penetrate to the neighboring enterocytes through cell-to-cell spread. (2) Beneath the epithelial cells, the basement membrane halts the spreading into the lamina propria. In response, they reinfect Peyer's patches (3), lamina propria macrophages (4), and other enterocytes (5). The *L. Monocytogenes* could spread in infected dendritic cells and/or macrophages through the portal vein directly to the liver (6) and all the way to the MLN (7). The MLN act another barrier and only one out of 100~1000 bacteria spread further to spleen and liver. Adopted from (Melton-Witt *et al.*, 2012).

from one single farm. A quick search of outbreaks in 2014 showed a total of 9 outbreaks in US with 55 illnesses and 51 patients were hospitalized and 13 deaths were occurred (CDC, 2015a). However in January, 2015, a total of 3 cases had been identified in King, Pierce, and Yakima counties of US. Among three, one illness was pregnancy-associated, two people were hospitalized and one death was reported. And finally, the company Queseria Bendita voluntary recalled the product from the market (Http://www.Outbreakdatabase. Com., 2015).

Control of foodborne pathogens: A series of foodborne outbreaks involving microbes in butter, beef, peanuts and poultry products has compelled the stakeholders to recognize the urgent need for technological means of ensuring the biological integrity of foods. Thus, industry experts realize the importance of novel technologies and their role in food security and safety (Rahman *et al.*, 2016; Khan and Oh, 2016). As health awareness among consumer increased, therefore, concern on the quality and safety of food is growing (Rahman *et al.*, 2012; Rahman *et al.*, 2011). Foodborne illness have increased in recent times (Rahman *et al.*, 2011; Rahman *et al.*, 2010a). Immediate steps are needed to be taken to control and prevent the incidence of these pathogens in food supply. Adopting technologies, agents and new practices for controlling SFP and SEs are established and their effects on pathogen and foodstuff have to be studied carefully. However, complete elimination of the pathogen from the food supply is hardly possible, but incidence necessarily be decreased and high level of growth prevented. Furthermore, all the strains of *L. Monocytogenes* show variation in terms of adaptation to environments, virulence and resistance to adverse conditions. Prevention and control of the Listeriosis is dependent on the effective management of pathogen that entails minimizing the chances of pathogen entry to food chain. Adoption of new technologies, agents and new practices for controlling *L. Monocytogenes* are well established and their effectiveness can be seen in Table 2 and 3.

Thus, exploring some effective sanitizers in order to remove pathogens in agricultural products and food is one of the significant steps in food industry which is an integral part of any Hazard Analysis and Critical Control Points (HACCP) in the industry (Rahman *et al.*, 2010b). Food industry has keenly overlooked on a number of non-thermal decontamination methods since its development. Hydrogen peroxide, acidified sodium chlorite, chlorine dioxide, warm water, sulfur dioxide, calcium chloride, ozone, sodium hypochlorite, electrolyzed water and other organic acids are some of the sanitizers currently in application for food processing (Rahman *et al.*, 2010a; Forghani *et al.*, 2015). Other clean-up methods include thermal pasteurization, dielectric heating, pulsed electric field, high pressure processing, microwave, and ohmic heating. Preservation methods can be biological, physical or chemical and the choice of food preservation technique employed depends on methods of inactivation or certain preservation factors (N.V.A., 2014).

Conclusion: FBP are growing with passage of time and became a serious threat for scientist around the world. Still, protecting the contamination of food chain from these pathogens is daunting, but not an impossible task. The chances of contamination in foods and food processing plants could be reduced. It is necessary to identify the various sources that bring the contaminant and investigate the possible mechanism by which the pathogen acquires entry to the food chain. Moreover, food materials can be subjected to various disinfection techniques in order to reduce the chances of contamination and ensure food safety. More than one disinfection technique may be applied to ensure microbial inhibition in the food products. Introducing novel decontamination strategies to food industry is highly important with less effect on food materials and their quality. The effective control of FBP in the near future will require effective public health setups that will promptly identify and respond to them and will prevent emerging problems.

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REFERENCES

Abubakar, I., L. Irvine, C. Aldus, G. Wyatt, R. Fordham, S. Schelenz, L. Shepstone, A. Howe, M. Peck and P.A. Hunter, 2007. Systematic review of the clinical, public health and cost-effectiveness of rapid diagnostic tests for the detection and identification of bacterial intestinal pathogens in faeces and food. Health Technol. Assess., 11: 1-216.

Adak G., S. Long, S. O'brien, 2002. Trends in indigenous foodborne disease and deaths, england and wales: 1992 to 2000. Gut, 51: 832-841.

Allerberger, F., M. Wagner, 2010. Listeriosis: A resurgent foodborne infection. Clin. Microbiol. Infect., 16: 16-23.

Argudín, M.Á., M.C. Mendoza and M.R. Rodicio, 2010. Food poisoning and *Staphylococcus aureus* enterotoxins. Toxins, 2: 1751-1773.

Asahata, S., Y. Hirai, Y. Ainoda, T. Fujita, Y. Okada, K. Kikuchi, 2015. Fournier's gangrene caused by *Listeria monocytogenes* as the primary organism. Can. J. Infect. Dis. Med. Microbiol., 26: 44.

Balaban, N., A. Rasooly, 2000. Staphylococcal enterotoxins. Intl. J. Food Microbiol., 61: 1-10.

Cain, D.B. and V.L. McCann, 1986. An unusual case of cutaneous listeriosis. J. Clin. Microbiol., 23: 976-977.

CDC, 2015a. Center of control diseases and prevention. Foodborne outbreak online database. Available at: Http://wwwn.Cdc.Gov/foodborneoutbreaks/.

CDC, 2015b. Centre of control diseases and prevention. Outbreak of staphylococcal food poisoning from a military unit lunch party - United States, july 2012. Available at: http://www.cdc.gov/ mmwr/preview/ mmwrhtml/mm 6250a2.Htm.

Chaibenjawong, P., S.J. Foster, 2011. Desiccation tolerance in staphylococcus aureus. Arch. Microbiol., 193: 125-135.

Chiang, Y.-C., W.-W. Liao, C.-M. Fan, W.-Y. Pai, C.-S. Chiou and H.-Y. Tsen, 2008. PCR detection of staphylococcal enterotoxins (ses) n, o, p, q, r, u, and survey of se types in *Staphylococcus aureus* isolates from food-poisoning cases in taiwan. Intl. J. Food Microbiol., 121: 66-73.

Cossart, P., 2011. Illuminating the landscape of host–pathogen interactions with the bacterium *Listeria monocytogenes*. Proceedings of the National Academy of Sciences, 108: 19484-19491.

Crim, S.M., M. Iwamoto, J.Y. Huang, P.M. Griffin, D. Gilliss, A.B. Cronquist, M. Cartter, M. Tobin-D'Angelo, D. Blythe and K. Smith, 2014. Incidence and trends of infection with pathogens transmitted commonly through food-foodborne diseases active surveillance network, 10 us sites, 2006-2013. MMWR Morb. Mortal. Wkly. Rep., 63: 328-332.

Crum, N.F., 2002. Update on *Listeria monocytogenes* infection. Curr. Gastroenterol. Rep., 4: 287-296.

De Buyser M.-L., B. Dufour, M. Maire and V. Lafarge, 2001. Implication of milk and milk products in food-borne diseases in France and in different industrialised countries. Int. J. Food Microbiol., 67: 1-17.

Dinges M.M., P.M. Orwin, P.M. Schlievert, 2000. Exotoxins of staphylococcus aureus. Clin. Microbiol. Rev., 13: 16-34.

Farber, J. and P. Peterkin 1991. *Listeria monocytogenes*, a food-borne pathogen. Microbiol. Rev., 55: 476.

Food and Drug Administration (FDA), 2008. Draft compliance policy guide sec. 555.320 *Listeria monocytogenes*; notice of public meeting. Federal Regulations, 73: 7298-7310.

Fleming, D.W., S.L. Cochi, K.L. MacDonald, J. Brondum, P.S. Hayes, B.D. Plikaytis, M.B. Holmes, A. Audurier, C.V. Broome and A.L. Reingold, 1985. Pasteurized milk as a vehicle of infection in an outbreak of listeriosis. N. Eng. J. Med., 312: 404-407.

Fletcher, S.M., L. Boonwaat, T. Moore, R. Chavada, S. Conaty, 2015. Investigating an outbreak of staphylococcal food poisoning among travellers across two australian states. West. Pac. Surveill. Res., 6.

Forghani, F., J.-H. Park, D.-H. Oh, 2015. Effect of water hardness on the production and microbicidal efficacy of slightly acidic electrolyzed water. Food Microbiol., 48: 28-34.

Fretz, R., J. Pichler, U. Sagel, P. Much, W. Ruppitsch, A. Pietzka, A. Stöger, S. Huhulescu, S. Heuberger, G. Appl, 2010. Update: Multinational listeriosis outbreak due to ‘quargel’, a sour milk curd cheese, caused by two different *L. Monocytogenes* serotype 1/2a strains, 2009-2010.

Food Standard Agency (FSA), 2015. Annual report of the chief scientist 2006/07. Accessed on 17.10.2015, available at http://www.Food.Gov.Uk/multimedia/pdf /board/fsa071005a.Pdf.

Gerner-Smidt, P., M. Weischer, A. Jensen, and W. Fredriksen, 1995. Listeriosis in denmark-results of a 10-year survey. XII International Symposium on Problems of Listeriosis, Perth, Western Australia, Australia, Promaco Conventions Pty Ltd.

Gray, M.L., A. Killinger, 1966. *Listeria monocytogenes* and listeric infections. Bacteriol. Rev., 30: 309.

Hennekinne, J.-A., M.-L. De Buyser and S. Dragacci, *Staphylococcus aureus* and its food poisoning toxins: Characterization and outbreak investigation. FEMS Microbiol. Rev., 36: 815-836.

Http://www.Outbreakdatabase.Com., 2015. Foodborne illness outbreak database. Accessed on 5-12-2015.

Hussain, M., 2013. Economic implications of microbiological food safety scares. NZ. Food Technol., 48: 33.

Ivanek, R., Y.T. Gröhn and M. Wiedmann, 2006. *Listeria monocytogenes* in multiple habitats and host populations: Review of available data for mathematical modeling. Foodbourne Path. Dis., 3: 319-336.

Johler, S., P.S. Tichaczek-Dischinger, J. Rau, H.-M. Sihto, A. Lehner, M. Adam, R. Stephan, 2013. Outbreak of staphylococcal food poisoning due to sea-producing staphylococcus aureus. Foodborne Path. Dis., 10: 777-781.

Jones, T.F., M.E. Kellum, S.S. Porter, M. Bell and W. Schaffner, 2002. An outbreak of community-acquired foodborne illness caused by methicillin-resistant. Emerg. Infect. Dis., 8: 83.

Kadariya, J., T.C. Smith and D. Thapaliya, 2014. *Staphylococcus aureus* and staphylococcal food-borne disease: An ongoing challenge in public health. BioMed Res. Int., 2014.

Kérouanton A., J. Hennekinne, C. Letertre, L. Petit, O. Chesneau, A. Brisabois, M. De Buyser, 2007. Characterization of *Staphylococcus aureus* strains associated with food poisoning outbreaks in France. Intl. J. Food Microbiol., 115: 369-375.

Khan, I. and D.-H. Oh, 2016. Integration of nisin into nanoparticles for application in foods. Innov. Food Sci. Emerg. Technol., 34: 376-384.

Kitamoto, M., K. Kito, Y. Niimi, S. Shoda, A. Takamura, T. Hiramatsu, T. Akashi, Y. Yokoi, H. Hirano and M. Hosokawa, 2009. Food poisoning by *Staphylococcus aureus* at a university festival. Jpn. J. Infect. Dis., 62: 242-243.

Le Loir Y., F. Baron and M. Gautier, 2003. *Staphylococcus aureus* and food poisoning. Genet. Mol. Res., 2: 63-76.

Lukinmaa, S., 2003. *Salmonella enterica, Listeria monocytogenes* and clostridium perfringens. Thesis publications of the National Public Health Institute, Finland.

Melton-Witt, J.A., S.M. Rafelski, D.A. Portnoy, A.I. Bakardjiev, 2012. Oral infection with signature-tagged *Listeria monocytogenes* reveals organ-specific growth and dissemination routes in guinea pigs. Infect. Immun., 80: 720-732.

Miya, S., H. Takahashi, T. Ishikawa, T. Fujii, B. Kimura, 2010. Risk of *Listeria monocytogenes* contamination of raw ready-to-eat seafood products available at retail outlets in japan. Appl. Env. Microbiol., 76: 3383-3386.

Murry, E., R. Webb and M. Swann, 1926. Disease of rabbits characterized by large mononuclear leucocytosis caused by a hither to undescribed bacterium Bacillus monocytogenes (n. Sp.). J. Pat. Bact., 29: 407-439.

N.V.A., 2014. Encyclopedia of agriculture and food systems, 2nd ed, academic press, 5.

Rahman, S., T. Ding and D.-H. Oh, 2010a. Effectiveness of low concentration electrolyzed water to inactivate foodborne pathogens under different environmental conditions. Intl. J. Food Microbiol., 139: 147-153.

Rahman, S., T. Ding and D.-H. Oh, 2010b. Inactivation effect of newly developed low concentration electrolyzed water and other sanitizers against microorganisms on spinach. Food Control, 21: 1383-1387.

Rahman, S., Y.-G. Jin, D.-H. Oh, 2011. Combination treatment of alkaline electrolyzed water and citric acid with mild heat to ensure microbial safety, shelf-life and sensory quality of shredded carrots. Food Microbiol., 28: 484-491.

Rahman, S., J.H. Park, J. Wang, D.-H. Oh, 2012. Stability of low concentration electrolyzed water and its sanitization potential against foodborne pathogens. J. Food Eng., 113: 548-553.

Rahman, S. M. E., Imran Khan, and Deog-Hwan Oh, 2016. "Electrolyzed water as a novel sanitizer in the food industry: current trends and future perspectives." Compr. Rev. Food. Sci. F., 15: 471-490.

Roberts, D. and M. Greenwood, 2003. Practical Food Microbiol.. Wiley Online Library: 2003.

Safety, F. *2015. Staphylococcus aureus* a problem when food is left out too long. Available at: Http://ohioline.Osu.Edu.

Sauders, B.D. and M. Wiedmann, 2007. Ecology of listeria species and *L. Monocytogenes* in the natural environment. Food Sci. Technol., 161: 21.

Scallan, E., P.M. Griffin, F.J. Angulo, R.V. Tauxe, R.M. Hoekstra, 2011a. Foodborne illness acquired in the United States-unspecified agents. Emerg. Infect. Dis., 17: 16.

Scallan, E., R.M. Hoekstra, F.J. Angulo, R.V. Tauxe, M.-A. Widdowson, S.L. Roy, J.L. Jones and P.M. Griffin, 2011b. Foodborne illness acquired in the United States-major pathogens. Emerg. Infect. Dis., 17.

Schlech III, W.F., P.M. Lavigne, R.A. Bortolussi, A.C. Allen, E.V. Haldane, A.J. Wort, A.W. Hightower, S.E. Johnson, S.H. King, E.S. Nicholls, 1983. Epidemic listeriosis-evidence for transmission by food. N. Eng. J. Med., 308: 203-206.

Schmid, D., R. Fretz, P. Winter, M. Mann, G. Höger, A. Stöger, W. Ruppitsch, J. Ladstätter, N. Mayer and A. de Martin, 2009. Outbreak of staphylococcal food intoxication after consumption of pasteurized milk products, june 2007, austria. Wiener klinische Wochenschrift, 121: 125-131.

Swaminathan, B., T.J. Barrett, S.B. Hunter, R.V. Tauxe, C.P.T. Force Pulsenet, 2001. The molecular subtyping network for foodborne bacterial disease surveillance, United States. Emerg. Infect. Dis., 7: 382.

Swaminathan, B. and P. Gerner-Smidt, 2007. The epidemiology of human listeriosis. Microb. Infect., 9: 1236-1243.

Tappero, J.W., A. Schuchat, K.A. Deaver, L. Mascola, J.D. Wenger, B. Swaminathan, P.S. Hayes, L.M. Graves, M.W. Reeves, R.E. Weaver, 1995. Reduction in the incidence of human listeriosis in the United States: Effectiveness of prevention efforts? JAMA, 273: 1118-1122.

Tauxe, R.V., 2002. Emerging foodborne pathogens. Int. J. Food Microbiol., 78: 31-41.

Todd, E., 1996. Epidemiology of foodborne diseases: A worldwide review. World health statistics quarterly. Quarterly World Health Statistics, 50: 30-50.

Tango, C.N., I. Khan, Y.S. Park and D.H. Oh, 2016. Growth of Staphylococcus aureus in cooked ready-to-eat ground fish as affected by inoculum size and potassium sorbate as food preservative. LWT-Food Sci. Technol., 71: 400-408.

Viswanathan, V., K. Hodges and G. Hecht, 2009. Enteric infection meets intestinal function: How bacterial pathogens cause diarrhoea. Nat. Rev. Microbiol., 7: 110-119.

Wieneke, A., D. Roberts, R. Gilbert, 1993. Staphylococcal food poisoning in the united kingdom, 1969-90. Epidemiol. Infect., 110: 519-531.