Bacterial biofilms and their new control strategies in food industry

Meltem Yesilcimen Akbas

Department of Molecular Biology and Genetics, Gebze Technical University, Gebze-Kocaeli, 41400 Turkey

Biofilm is a multicellular layer of adherent bacteria surrounded by organic polymer matrix. The development of biofilms in food processing environments is a potential source of hazard for food safety and quality [1]. Food contact surfaces are commonly disinfected with different chemical compounds. However, corrosion and toxicity limit the use of these commercial disinfectants [2]. The risk will become more serious, if the bacteria in biofilm increase their resistance to disinfectants [3]. This book chapter provides a contribution to better understand and highlights the importance and relevance of pathogenic food-borne bacteria and their associated biofilm formations, factors affecting their biofilm formations and new natural potential biofilm control strategies compared with commercial disinfectants in food industry.

Keywords: food-borne bacteria; food contact surfaces; biofilm prevention; biofilm removal

1. Introduction

The control of food borne pathogens has received a great deal of attention for the last decade, because these organisms can readily form biofilms on the different surfaces [4]. Biofilm is a multicellular layer of adherent bacteria enclosed by polymeric matrix [5, 6]. The attachment of different bacteria with subsequent development of biofilms on food processing surface can lead food spoilage or transmission of diseases [7-9]. Bacteria detached from the biofilms are potential sources of contamination and can cause significant damage to food quality. The formation and development of biofilms depend on different factors including strain of bacteria [10, 11], attachment surface material and environmental parameters such as the pH, temperature and nutrients [12]. Biofilm formation provides survival of bacteria under environmental stress conditions as ultraviolet radiation, physicochemical stresses or insufficient supply of nutritive resources. In addition, bacteria in biofilms can be up to 10 to 1000 times more resistant to the effects of antimicrobial agents than planktonic bacterial cells [13-15].

Food contact surfaces are widely treated with chemical disinfectants that contain peroxides, chloramines or hypochlorites [16, 17]. The disinfectant compounds must be effective for both inactivating pathogens and maintaining quality of the product [18]. Moreover; corrosion, product contamination, and toxicity could limit the use of these commercial chemical compounds [19]. The resistance of biofilm forming microorganisms to these antimicrobial agents indicated that there is a great need of developing new and safe antibiofilm agents for food industry [20]. Therefore, the interest in natural antimicrobials for biofilm formations has increased in recent years [21]. Although there are several researches on both biofilm formations and their effective and safe control strategies, there is still a big gap in the literature. The purpose of this book chapter is to provide new and relevant knowledge for the biofilm formations of food-borne bacteria and new natural potential biofilm control strategies compared with commercial disinfectants in food industry.

2. Biofilm Formation

2.1 Biofilm formation processes

A biofilm is composed of complex communities of bacteria mostly with mixed species that is irreversibly attached to different surface materials. This structure is enclosed in a matrix of primarily polysaccharide material and a mix of proteins, lipids, and nucleic acids forming a single layer or three-dimensional structures [22-24]. Moreover, mature biofilms are well organized structures in which water channels are dispersed and can provide passages for the exchange of nutrients, metabolites and waste products [23]. Bacterial growth and biofilm formation on solid material is a five-step process [5, 25, and 26] (Fig. 1).

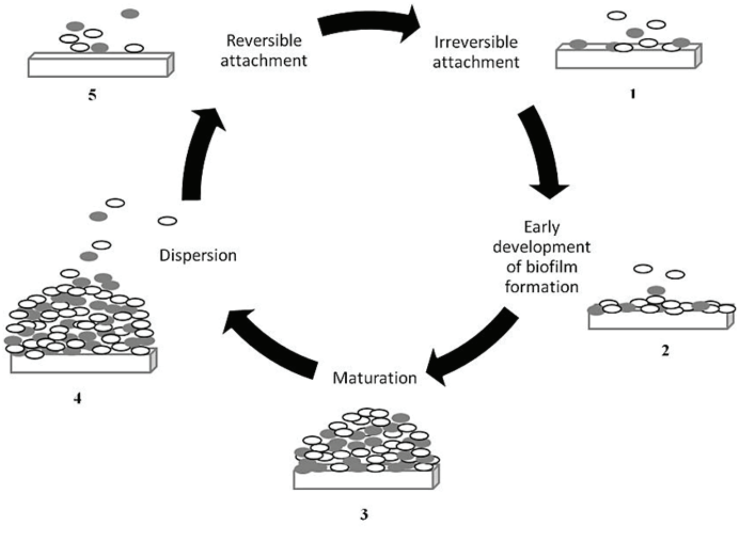

Fig. 1 A simplified schematic diagram of a five-step biofilm formation and detachment.

2.1.1 Initial reversible attachment

Biofilm formation starts with the attachment of planktonic bacteria to solid surfaces. The reversible attachment is attained between bacteria and surface through van der Waals and electrostatic forces [27]. Most of the bacteria are negatively charged the electrostatic interactions tend to facilitate the repulsion [28]. However, the positive charge of *Stenotrophomonas maltophilia* could cause reversible attachment to negatively charged material such as Teflon [29, 6]. The direct contact with the surface material occurs via the surface appendages of bacteria such as flagella, fimbriae and extracellular polymers [30-32].

2.1.2 Irreversible attachment

The biofilm grows through a process of cell division and reversible attachment. This attachment, then, differentiates to irreversible attachment with the production of extracellular polymers (EPS) by the bacteria. In the irreversible phase, the interactions are dipole-dipole, hydrophobic, ion-ion ion-dipole, covalent bonds and hydrogen interactions [33, 34]. In addition, bacterial cells up regulate the expressions of specific attachment-related genes within a few minutes of their attachment to the surface [35].

2.1.3 Early development of biofilm structure

The EPS layer strengthens the structure between bacterial cells and the substratum. Over a period of time, the interactions and bonds are strengthened, making the attachment irreversible.

2.1.4 Maturation

During the maturation, the biofilm develops into an organized resistant structure to toxic chemicals and disinfectants. The irreversibly attached cells grow more by using available nutrients from the surrounding fluid environment and form microcolonies.

2.1.5 Dispersion

Bacterial cells are released from biofilm into the surrounding environment. The detachment of cells from the surface can be regulated by own population density-dependent gene expression (Quorum sensing, QS) controlled by extracellular signalling molecules such as acly-homoserine lactones (AHLs) for Gram-negative bacteria or oligopeptides for Gram-positive bacteria [36]. The detached bacteria find new locations and restart the new biofilm formation [37].

3. Molecular mechanisms for biofilm formation and detachment

The molecular mechanisms of biofilm formation in food processing industry are getting higher attention in recent years [38-40]. From the initial interaction with surfaces, significant changes in expression of many genes occur in the bacterial cells [41-46]. This process includes a number of up- and down-regulation of a number of genes [47-49]. It was shown that *algC* up-regulation in individual bacterial cells within minutes of attachment to surfaces [47]. Prigent-Combaret et al. [48] found that 22% of these genes were up-regulated in the biofilm state, while 16% were down-regulated in *E. coli*. In a recent study, formation of physical contact between the bacterium and the surface initiated adhesin production in *Caulobacter crescentus* [49].

Quorum sensing (QS) is a communication between bacteria to provide information about cell density for adjusting their own gene expression properly. QS process includes production and sensing of signal molecules such as auto inducers [50]. Many of bacterial behaviour and physiological processes such as growth, pathogenicity, sporulation, and biofilm formation are regulated by QS [51-53]. QS contributes to biofilm formation by many different bacteria, but its role in food related biofilm structures has not been completely clarified yet. Quorum-sensing controlled expression of surfactant molecules is important for biofilm forming and dispersion. In *staphylococci*, the accessory gene regulator (*agr*) quorum-sensing system mediates biofilm detachment [54, 55]. Some of the surfactant-like molecules produced by bacteria to establish and detach biofilms are surfactins [56-57], rhamnolipids [58, 59] and the surfactant peptides [60].

4. Factors affecting biofilm formations

The attachment of microorganisms to surfaces is a very complex process. In the process of a dynamic and complex biofilm formation, properties of solid material, hydrophobicity of both material and cell surface, production of extracellular polymeric substances, and environmental factors such as nutritional properties of the food matrix, availability of moisture and nutrients, the pH level, the temperature of the contact surface and even the presence of other bacteria play important roles [61-64]. In general, rougher, and more hydrophobic surfaces are preferred attachment

© FORMATEX 2015

sides at the beginning of the biofilm formation. An increase in flow velocity, temperature, or nutrient concentration could also increase attachment, if these parameters are at optimal levels for bacterial growth.

4.1 Physical properties of the contact surface material

Food contact surface materials have substantial effect on the attachment and biofilm formation. The materials used for food contact surfaces are mostly stainless steel, glass, rubber, polyurethane [65], Teflon, nitrile butyl rubber (NBR, Buna-n) [66], and may be wood in some countries [67]. The adhesion to the abiotic surface is affected by the physicochemical characteristics of the surface material such as roughness [12], surface charge [68], hydrophobicity [12], pH, temperature [69], and nutrient composition of the preconditioning solution [12, 70]. For instance, primary attachment of bacteria to stainless steel and Teflon was enhanced in the presence of surface-associated milk proteins [71]. Howell and Behrends [72] reported that the extent of microbial attachment was correlated with surface roughness. The surface roughness of a polyester urethane conveyor belt affected the biofilm forming ability of *L. monocytogenes* [73]. Hydrophobic/hydrophilic interactions are found to be effective for adhesion of bacteria to the abiotic surfaces [74, 75]. Metal surfaces are negatively charged and referred as hydrophilic as shown by water contact angles, while Teflon is less electrostatically-charged and referred as hydrophobic surface [76]. Previously, it was shown that hydrophobic surfaces were more resistant to bacterial adhesion than the hydrophilic surfaces [77-80]. However, Baker [81] could not determine any difference between hydrophilic glass and polystyrene plates for the attachment of freshwater bacteria. In another study, Sinde and Carballo [82] found that *Salmonella* and *Listeria* species can attach in higher numbers to hydrophobic surfaces than the hydrophilic ones. It was reported that *Salmonella* spp. and *L. monocytogenes* can produce biofilms on plastic surfaces [83]. It was also suggested that besides the material itself, parts of the food processing plants such as joints, corners, and equipment design can also affect biofilm formation [84].

4.2 Physiochemical properties of bacterial cells

Cell surface hydrophobicity, cell surface structures such as fimbriae, other proteins, EPS, and flagella play important roles in the attachment of bacteria to the substratum. Fimbriae, some proteins, and mycolic acids of Gram-positive bacteria play major role for attachment to hydrophobic surfaces. EPS and lipopolysaccharides are more important in attachment to hydrophilic materials. In addition, attachment is facilitated by different adhesive organelles, e.g., flagella and type IV pili play important roles in attachment of *Pseudomonas* spp. and *Vibrio cholera*, whereas fimbriae like type 1 pili, curli, and conjugative pili are important for biofilm formation in *E.coli* [85-88]. Different types of fimbriae involve to the attachment such as type 1 fimbriae, curli, type 4 pili, long polar fimbriae, and F9 fimbriae in the attachment of Shiga-toxin producing *E. coli* (STEC) to surfaces [89].

4.3 Biosynthesis of extracellular polymers

Exopolysaccaride (EPS) molecules are accepted as a major factor affecting the biofilm formation. EPS molecules strengthen the interactions between the bacteria for microcolony formation on abiotic substratum [5, 22]. EPS have different chemical and physical properties depending on their chemical composition [90]. They are composed of either homopolysaccharides or heteropolysaccharides. The EPS synthesis is affected by environmental factors such as carbon or nitrogen supply, pH value, culture temperature and oxygen concentration [75, 91, 92, and 93]. Leriche et al., [94] showed that different organisms produce different amounts of EPS and that the amount of EPS increases with age of the biofilm. EPS could be hydrophobic characteristics. However, most types of EPS are both hydrophilic and hydrophobic [90].

4.4 Other environmental factors

Biofilm formation on different substratum can be influenced by species of bacteria and environmental conditions (nutrient level, pH and temperature) [95]. Environmental conditions such as starvation and nutrient availability can start biofilm formation [93, 96]. In some of the laboratory research, nutritional starvation triggered the cell adhesion, whereas in other studies bacterial colonization process increased by high amount of nutrients [5, 96, and 97]. It was shown that both pH and temperature are important for bacterial adhesion to stainless steel surface [98, 99]. Fletcher [100, 101] reported that an increase in the concentration of cations such as sodium, calcium, lanthanum or ferric iron affected the attachment of *P. fluorescens* to glass surfaces.

5. Biofilms in Food industry

5.1 Food borne bacteria in food processing environments

Adhesion of bacteria to equipment surfaces could be the main reason for transmission of pathogens to food in the food processing industry [102, 103]. Inclusion of pathogens to surfaces can be either by directly or indirectly through airborne particles [104]. Cross-contamination from raw products through hands and utensils could lead to the outbreaks

© FORMATEX 2015

of foodborne illness [104]. Moreover, equipment surfaces in food processing industry are known as a major source of bacterial contamination [105]. Many of pathogenic bacteria including *Bacillus, Salmonella, Listeria, Staphylococcus* and *Escherichia* could attach and form biofilm on food processing environments such as metal, glass, plastic or rubber surfaces [106-110]. Metabolic interactions between these species contribute to the formations of biofilms, and the production of a dynamic local environment [111-112]. In food industry, biofilms with mixed-bacterial species are usually very stable and cell-to-cell interactions affect the biofilm formation, biofilm structure, and resistance to the antimicrobial treatments [113-117]. Although it is clear that many pathogenic bacteria can form biofilms in the food processing industry, the most important biofilm forming bacterial species in relation to food safety are listed below [118].

Listeria monocytogenes: *Listeria monocytogenes* is a Gram-positive opportunistic food-borne pathogen which causes outbreaks of listeriosis [119,120]. This bacterium can be found in many environments such as water, soil, sewage, and animal feces and survive for a long time [121,122]. *L. monocytogenes* can grow at refrigerated temperature, under high osmotic pressure (10% NaCl), and at a wide pH range (pH 4-9) [123]. *L. monocytogenes* in food processing environments can adhere to many different surfaces and forms biofilms [124-128]. *Listeria* utilizes flagella, pili, and membrane proteins for attachment to surfaces [129]. It was shown that *Listeria* can form biofilms on slicers and other steel utensils [130].This can cause further cross contamination of this pathogenic bacteria.

Salmonella spp.: *Salmonella* was the first reported foodborne bacteria adhering to food surfaces for biofilm formation [131]. Several studies have shown that *Salmonella* can attach and form biofilms on surfaces found in food-processing environments such as plastic and stainless steel surfaces [132, 133]. *Salmonella has* a cell-surface appendage (SEF-17 *fimbriae*) for attachment to surfaces and resistance to mechanical forces [118].

Escherichia coli: *E. coli* can form biofilms through their flagella, pili, and membrane proteins for their adhesion. After adhesion to the different surfaces *E.coli* loses its flagella and produces sticky extracellular polysaccharides [118, 134]. Many species of the *Enterobacteriaceae* family including *E. coli* produce cellulose for the survival of the bacteria in the environment stress conditions [135].

Pseudomonas spp.: *Pseudomonas* spp. are major pathogenic bacteria on dairy product, poultry and meat processing industry [136, 137]. In the dairy food industry, the psychotropic *Pseudomonas* are the most frequently found bacteria causing deterioration of raw milk stored at refrigerated temperature. Its rapid growth at refrigeration temperatures and production of exopolysaccharides provides the *Pseudomonas* with a great ability of biofilm formation [138]. *Pseudomonas* strains are more resistant to chemicals when they found as mixed cultures within biofilms with *Listeria*, *Salmonella* and other pathogens [118, 133].

Bacillus spp.: *Bacillus* spp. is found and survives in dairy processing industry especially in pipelines and joints [118, 133]. *Bacillus cereus* is often forming mixed biofilms with other bacterial species in the food [139,140] and beverage industries [141]. High levels of *Bacillus* biofilms have been reported in dairy processing industries [142].

5.2 Use of antibiofilm agents in food industry

Biofilms are a great concern in food industry. There have been many research activities on the prevention and eradication of biofilm formations for many years [133, 143, and 144]. The commercial chemical compounds used as sanitizers in the food processing industry are chlorine-based sanitizers, iodine and quaternary ammonium compounds. Below is a brief description of some of disinfectants that are commonly used in food processing environments.

Chlorine-based sanitizers and peracetic acid (PAA) are frequently used in food processing industry such as washing fruits and vegetables and sanitizing food contact surfaces. They are easy to prepare and apply, and economical. The maximum allowable level for food contact without a rinse step is 200 ppm available chlorine [145]. Hypochlorides are the most effective chlorine compounds among chlorinated sanitizers. Chlorine mixed with sodium (sodium hypochlorite, NaClO) used for sanitization of food-contact surfaces [144]. The major disadvantages of chlorine compounds are their decreasing solubility in water and increasing corrosiveness to metal surfaces with a higher temperature. There is also a great concern based upon the involvement of chlorine in the formation of trihalomethanes (THMs) which are carcinogenic under certain conditions [146]. In addition, chlorine can also irritate skin and mucosal membrane.

Peroxyacetic acid (Peracetic acid, PAA) is a mixture of acetic acid and hydrogen peroxide in an aqueous solution used as a disinfectant for fruits, vegetables, meat, and eggs and also as a sanitizer for food contact surfaces for a potential replacement for chlorine applications [147]. PAA leaves no toxic residues, thus, it can be applied without rinsing. PAA is also effective on biofilm forming bacteria especially if the biofilm contains food residues [133]. However, PAA can be corrosive for the surface materials. Furthermore, exposure to PAA can cause irritation to the skin, eyes and respiratory system and permanent lung damage or asthma [148]. In addition to its disadvantages, another drawback is that it is not cheap and increases organic content in the effluent [149].

Iodophors are a combination of non-iodine-wetting agents and iodine. The primary disadvantages are that iodine can affect the flavor and odor of food and cause staining on some surfaces (especially plastics). In the hot environmental conditions iodine can vaporize and can be corrosive to equipment.

Quaternary ammonium compounds (QAC) are widely used in disinfection treatments in food industry [150]. However, the broad application of QACs in food industries can cause the microbial growth and adaptation [151, 152].

5.3 Novel safe approaches for the control of biofilm formations

Bacteria in biofilms have enhanced resistance to chemical sanitizers. In addition, these sanitizer residues are designated as toxic [153-156]. The interest in natural antimicrobials has increased in recent years [21]. In particular, these biologic sources are enzymes, phages and microorganisms originated antimicrobial compounds [157] or natural plant molecules [158].

Plant-derived compounds such as many essential oils have been evaluated for their antimicrobial and antibiofilm activities against food-borne pathogens in several studies [159-162]. Sandasi et al., [163] assessed the antibiofilm activities of plant extracts on *L. monocytogenes* biofilms on polyvinyl chloride (PVC) surface and found that the plant extracts could inhibit biofilm formation and reduce the biofilm growth.

Polysaccharides can inhibit the biofilm formation of bacteria, possibly by modifying the physical properties of both abiotic and biotic surfaces [164]. It was shown that *E. coli* exopolysaccharides can alter the abiotic surface properties such as increase the hydrophobicity of glass surfaces and also can prevent cell-to cell auto aggregation via adhesions of bacteria [165,166].

Enzymes could also be possible alternative treatments as natural antibiofilm agents. Serine proteases were efficiently reducing *Bacillus* biofilms whereas polysaccharides remove more efficiently *Pseudomonas fluorescens* than serine proteases [167]. Polysaccharide polymerases and esterase can also control biofilm formations [168,169].

Nisin is an extracellular protein produced by some strains of *Lactococcus lactis* and has been employed as an anti-biofilm agent [170]. Nisin is a Generally Recognized as Safe (GRAS) substance. It has been approved in the EU (as additive E234) and by the US Food and Drug Administration (FDA) [171]. Nisin has a mode of action that results in the formation of pores in the cell membrane of the bacteria. Pore formation leads to cell lysis and death. The bactericidal activity of nisin has been shown to target other Gram positive bacteria closely related to *Lactococcus lactis* and some Gram positive pathogens, such as *Listeria monocytogenes* [172]. Nisin is effective against planktonic cells of multi-drug resistant staphylococci [173, 174].

Quorum sensing inhibition is also an attractive natural antibiofilm strategy [157]. Among QS inhibitors, halogenated furanones are produced by the marine alga *Delisea pulchra* [175,176]. Rhamnolipids from *P. aeruginosa* and surfactin from *B. subtilis* were found to be effective against mixed-species biofilms of S. *aureus*, *L. monocytogenes*, and *S. enteritidis* for both mono and mixed species of biofilms [177]. Lipopeptide biosurfactants from *Paenibacillus polymyxa* have also inhibitory effect on both single and mixed species biofilms such as *B. subtilis*, *P. aeruginosa* and *S. aureus* [178].

Another approach receiving attention is the use of organic acids (citric, malic, gallic acids etc.) as antibiofilm strategies. Organic acids are widely distributed in plants and animals. They are considered to be safe in terms of human and animal health with no toxic residues. Organic acids can be as effective as chemical disinfectants. Moreover, using organic acids could also help to reduce the use of chemical agents, water consumption, and energy cost.

Organic acids were shown as antimicrobial compounds against many pathogenic bacteria [179, 180]. The antimicrobial effect of organic acids could depend on several factors such as side chain composition, hydrophobicity or chain length [181]. It was also reported that different types of organic acids exerts different antimicrobial effects against bacteria [182]. It is also known that weak organic acids are lipophilic, can penetrate plasma membrane and acidify the cell's cytoplasm. As bacteria maintain a neutral pH of the cytoplasm, bacteria export of excess protons to maintain the pH of the cytoplasm and thus, consume cellular ATP and results in depletion of energy. Organic acids may inhibit membrane function and nutrient transport, prevent synthesis of macromolecules and denature DNA [183].

Citric acid is a hydroxyl tricarboxylic acid produced naturally by various plants. It is also affirmed as Generally Recognized as Safe (GRAS, 21CFR184.1033), and approved for use in the manufacture of fresh and processed meats and poultry at specific concentrations [184]. Citric acid inhibits bacterial cells via metal chelation which are vital for bacterial growth. Previously, it was found that dipping of fresh-cut iceberg lettuce in 0.5% citric acid solution for 2 min could be as effective as chlorine solution at 100 ppm for reducing pathogenic microorganisms [180]. It was reported that the biofilm forming heterotrophic and coliform bacteria inactivated about 99% by citric acid treatment on the surface of polyvinyl chloride (PVC) pipes [185]. Lieleg et al., [186] reported that citric acid can be a fluidization agent for established biofilm formations and this organic acid affects the *P.aeruginosa* biofilm elasticity.

Citric acid treatment can be used as an alternative disinfectant in controlling biofilm formation in the dairy industry. Recently, the prevention and removal of biofilm formation of *S. aureus* strains isolated from raw milk by citric acid treatments (2% and 10%) for 20 min were assessed for comparison with peracetic acid treatment (0.3%) on both on microtitration plate and stainless steel coupons [187]. The prevention and removal of biofilm formation ratios and the numbers of prevented or removed *S. aureus* strains were observed to be higher by using citric acid treatments compared with peracetic acid treatment on both surfaces. Moreover, the prevention and removal of biofilm formation were substantially higher when the concentration of citric acid treatment increased from 2% to 10% and the stainless coupons were used.

Gallic acid is one of the abundant phenolic products found in plants such as tea leaves, fruits and flowers [188]. It has been shown that gallic acid has strong antimicrobial activity against several bacterial strains [189]. Borges et al., [190] also reported antibiofilm activity of gallic acid for the prevention and removal of *E.coli*, *P. aeruginosa*, *S.*

aureus and *L.monocytogenes* biofilms. The researchers found that gallic acid can prevent and remove these pathogens by promoting reductions in biofilm activity >70% of all tested microorganisms.

Malic acid is a dicarboxylic acid found widely in many foods. The studies showed that it can be used to treat food borne pathogens [191-195]. The antimicrobial action of malic acid is to lower the pH value [196] or cause the significant damage to the cytoplasm of bacteria [197]. Singla et al., [198] found that malic acid was also effective in food industry for complete inhibition of *Salmonella* Typhimurium biofilm in carrot and other food contact surfaces. Therefore, the research on the use of organic acid treatments to control biofilms may be promising to overcome potential hazards of commercial chemical sanitizers to the human health and environment.

5.4 Conclusions and future directions

The biofilm formations of food-borne bacteria and natural potential biofilm control strategies are relatively a new research area in food microbiology. The state-of-the-art in using natural biofilm control strategies is presented here. The comparison of their activities with commercial disinfectants is also investigated in detail. The existing literature indicates that using natural antibiofilm agents can be used as potential control strategies for biofilm formations in food processing industry (Fig. 2). However, there are still no available commercialized natural antibiofilm products. This might be attributed to their excessive-cost or lack of financial interest [199]. The followings need to be considered and studied in future studies for using natural antibiofilm agents when they are used effectively and commercially:

a) Biofilms harbour mixed species of microorganisms. This phenomenon could lead to drastic enhancement in bacterial population resistance to the routinely applied sanitizers and potentially leading to the emergence of opportunistic pathogenic bacterial dispersion previously kept under control.

b) Intensive studies should determine the effects of different natural antibiofilm agents such as organic acids on different mono and mixed species of biofilm forming bacteria.

c) The studies should also be extended to control biofilm formation on different food processing surfaces such as teflon, glass. etc.

d) Continued research efforts in this area will lead to the identification of new effective natural antibiofilm strategies that may be used as a routine procedure for replacement of chemical sanitizers in the industry in the future.

e) New potent natural antibiofilm agents in the food industry should be required to evaluate carefully to determine validity and protection of human health and environment.

f) Additionally, it should be noted that validated use of natural agents combined with mechanical action could control biofilms more efficiently.

g) A concept of green technology by natural antibiofilm agents may have a promising future.

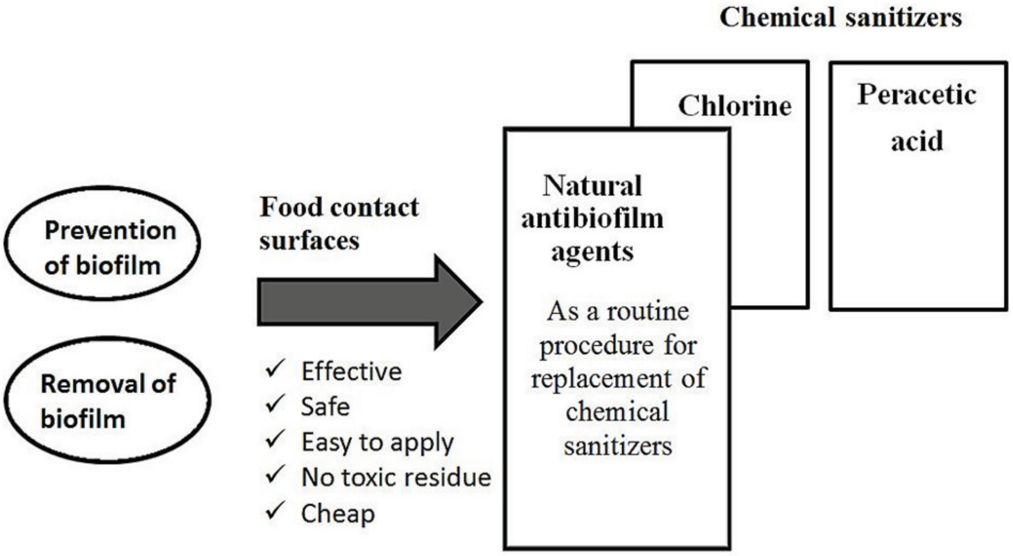

Fig. 2 A schematic illustration of natural antibiofilm agents as replacement strategy for chemical sanitizers.

References

[1] Oulahal N, Brice W, Martial A, Degraeve P. Quantitative analysis of survival of *Staphylococcus* aureus or *Listeria innocua* on two types of surfaces: Polypropylene and stainless steel in contact with three different dairy products. Food Control. 2008; 19: 178-185.

[2] Aarnisalo K, Lunden J, Korkeala H. Wirtanen G. Susceptibility of *Listeria monocytogenes* strains to disinfectants and chlorinated alkaline cleaners at cold temperatures. Food Science and Technology. 2007; 40: 1041-1048.

[3] Mosteller TM, Bishop JR. Sanitizer efficacy against attached bacteria in milk biofilm. Journal of Food Protection. 1993; 56: 34-41.

[4] Naves P, del Prado G, Huelves L, Gracia M, Ruiz V, Blanco J, Rodriguez-CerratoV, Ponte MC, Soriano F. Measurement of biofilm formation by clinical isolates of *Escherichia coli* is method-dependent. Journal of Applied Microbiology. 2008; 105:585–90.

[5] Costerton JW, Lewandowski Z, Caldwell DE, Korber DR, Lappinscott HM. Annual Review of Microbiology, 1995; 49:711–45.

[6] Costerton JW, Stewart PS, Greenberg EP. Bacterial biofilms: A common cause of persistent infections. Science. 1999; 284: 1318-22.

[7] Austin, JW, Berferin G. Development of bacterial biofilms in dairy processing lines. Journal of Dairy Research. 1995; 62: 509–19.

[8] Oulahal N, Brice W, Martial A, Degraeve P. Quantitative analysis of survival of *Staphylococcus aureus* or *Listeria innocua* on two types of surfaces: Polypropylene and stainless steel in contact with three different dairy products. Food Control. 2008; 19:178-185.

[9] Corcoran M, Morris D, De Lappe N, O'Connor J, Lalor P, Dockery P, Cormican M. Commonly used disinfectants fail to eradicate *Salmonella enterica* biofilms 344 from food contact surface materials. Applied and Environmental Microbiology. 2014; 80: 345 1507-14.

[10] Borucki MK, Peppin JD, White D, Loge F, Call DR. Variation in biofilm formation among strains of *Listeria monocytogenes*. Applied and Environmental Microbiology. 2003; 69: 7336-42.

[11] Chae MS, Schraft H. Comparative evaluation of adhesion and biofilm formation of different *Listeria monocytogenes* strains. International Journal of Food Microbiology. 2000; 62: 103–11.

[12] Donlan R M. Biofilms: microbial life on surfaces. Emerging Infectious Disease. 2002; 8(9): 881-90.

[13] Cos P, Tote K, Horemans T, Maes L. Biofilms an extra hurdle for effective antimicrobial therapy. Current Pharmaceutical Design. 2010;16: 2279-95.

[14] Zahin M, Hasan S, Aqil F, Khan MSA, Husain FM, Ahmad I. Screening of Indian medicinal plants for their anti-quorum sensing activity. Indian Journal of Experimental Biology. 2010; 48: 1219–24.

[15] Simoes M. Antimicrobial strategies effective against infectious bacterial biofilms. Current Medicinal Chemistry. 2011; 18: 2129-45.

[16] Dosti B, Guzel-Seydim Z, Greene A K. Effectiveness of ozone, heat and chlorine for destroying common food spoilage bacteria in synthetic media and biofilms. International Journal of Dairy Technology, 2005; 58: 19–24.

[17] Aarnisalo K, Lunden J, Korkeala H.. Wirtanen G.. Susceptibility of *Listeria monocytogenes* strains to disinfectants and chlorinated alkaline cleaners at cold temperatures. Food Science and Technology. 2007; 40: 1041-48.

[18] Bermúdez-Aguirre D, Barbosa-Cánovas GV. Disinfection of selected vegetables under nonthermal treatments: chlorine, acid citric, ultraviolet light and ozone. Food Control. 2012; 29: 82-90.

[19] Knowless JR, Roller S, Murray DB, Naidu AS. Antimicrobial action of carvacrol at different stages of dual species biofilm development by *Staphylococcus aureu*s and *Salmonella enterica* Typhimurium. Applied and Environmental Microbiology. 2005; 71: 797-803.

[20] Jabra-Rizk MA, Meiller TF, James CE, Shirtliff ME. Effect of farnesol on *Staphylococcus aureus* biofilm formation and antimicrobial susceptibility. Antimicrobial Agents and Chemotherapy. 2006;50:1463-1469.

[21] Saavedra MJ, Borges A, Dia, C, Aires A, Bennett RN, Rosa ES, Simões M. Antimicrobial activity of phenolics and glucosinolate hydrolysis products and their synergy with streptomycin against pathogenic bacteria. Medicinal Chemistry. 2010; 6: 174-183.

[22] Branda SS, Vik A, Friedman L, Kolter R. Trends Microbiology. 2005; 13:20–26.

[23] Sauer K, Rickard AH, Davies DG. Biofilms and biocomplexity. American Society for Microbiology. 2007; 2: 347-53.

[24] Flemming HC, Wingender J. The Biofilm Matrix. Nature Review Microbiology, 2010; 8: 623-33.

[25] Jefferson KK What drives bacteria to produce biofilm? FEMS Microbiology Letters. 2004; 236:163-73.

[26] van Houdt R, Michiels CW. Role of bacterial cell surface structures in *Escherichia coli* biofilm formation. Research in Microbiology 2005; 156:626–633.

[27] Miron J, Ben-Ghedalia D, Morrison M. Invited Review: Adhesion mechanisms of rumen cellulolytic bacteria. Journal of Dairy Science. 2001;84:1294–1309.

[28] Carpentier B, Cerf O. Biofilms and their consequences with particular references to hygiene in the food industry. Journal of Applied Bacteriology, 1993; 75: 499-511.

[29] Jucker BA, Harms H, Zehnder AJ. Adhesion of the positively charged bacterium *Stenotrophomonas* (*Xanthomonas*) *maltophilia* 70401 to glass and Teflon. Journal of Bacteriology. 1996; 178: 5472–79.

[30] Kumar CG, Anand SK. Significance of microbial biofilms in food industry:A review. International Journal of Food Microbiology. 1998; 42(1–2): 9–27.

[31] Cunliffe D, Smart CA, Alexander C, Vulfson EN. Bacterial adhesion at synthetic surfaces. Applied and Environmental Microbiology. 1999; 65: 4995–5002.

[32] Liu Y, Tay JH. Detachment forces and their influence on the structure and metabolic behaviour of biofilms. World Journal of Microbiology and Biotechnology. 2001; 17:111 – 17.

[33] Marshall KC, Stout R, Mitchell R. Mechanisms of the initial events in the sorption of marine bacteria to surfaces. Journal of General Microbiology 1971;68:337–48.

[34] Zottola EA. Microbial attachment and biofilm formation: A new problem for the food industry? Scientific Status Summary. Food Technology. 1994; 48(7): 107-14.

[35] Dunne WM. Bacterial adhesion: seen any good biofilms lately? Clinical Microbiology Reviews. 2002; 15 (2),155-166.

[36] Davies DG, Parsek MR, Pearson JP, Iglewski BH, Costerton JW, Greenberg EP. The involvement of cell-to-cell signals in the development of a bacterial biofilm. 1998; Science. 280. 295-8.

[37] Marshall K C. Biofilms: an overview of bacterial adhesion, activity, and control at surfaces. ASM News. 1992; 58(4)**:**202-207.

[38] Kim SH, Wei CI. Molecular characterization of biofilm formation and attachment of *Salmonella enterica* serovar Typhimurium DT104 on food contact surfaces. Journal of Food Protection. 2009; 72(9): 1841–1847.

[39] Smith JL, Fratamico PM, Uhlich G A. Molecular mechanisms involved in biofilm formation by food-associated bacteria. In P. M. Fratamico, B. A. Annous, & N. W. Gunther (Eds.), Biofilms in the food and beverage industries. Oxford, UK: Woodhead Publishing, Ltd. 2009; 42–98.

[40] Van Houdt R, Michiels CW Biofilm formation and the food industry, a focus on the bacterial outer surface. Journal of Applied Microbiology. 2010; 109:1117–31.

[41] Whiteley M, Bangera MG, Bumgarner R E, Parsek M R, Teitzel G M, Lory S, Greenberg EP. Gene expression in *Pseudomonas aeruginosa* biofilms. Nature. 2001. 413(6858): 860–864.

[42] Beloin C, Valle J, Latour-Lambert P, Faure P, Kzreminski M, Balestrino D, Haagensen JA, Molin S, Prensier G, Arbeille B, Ghigo JM. Global impact of mature biofilm lifestyle on *Escherichia coli* K-12 gene expression. Molecular Microbiology, 2004; 51(3): 659–674.

[43] Hamilton S, Bongaerts RJ, Mulholland F, Cochrane B, Porter J, Lucchini S, Lappin-Scott HM, Hinton J C. The transcriptional programme of *Salmonella enterica* serovar Typhimurium reveals a key role for tryptophan metabolism in biofilms. BMC Genomics. 2009; 10: 599.

[44] Shemesh M, Tam A, Steinberg D. Differential gene expression profiling of *Streptococcus mutants* cultured under biofilm and planktonic conditions. Microbiology. 2007;153:1307–17.

[45] Stewart, PS, Franklin MJ. Physiological heterogeneity in biofilms. Nature Reviews Microbiology. 2008; 6(3): 199–210.

[46] McDougald D, Rice SA, Barraud N, Steinberg P D, Kjelleberg S. Should we stay or should we go:Mechanisms and ecological consequences for biofilm dispersal. Nature Reviews Microbiology. 2011; 10(1): 39–50.

[47] Davies DG, Geesey GG. Regulation of the alginate biosynthesis gene *algC* in *Pseudomonas aeruginosa* during biofilm development in continuous culture. Applied and Environmental Microbiology. 1995;61:860–7.

[48] Prigent-Combaret C, Vidal O, Dorel C, Lejeune P. Abiotic surface sensing and biofilm-dependent regulation of gene expression in *Escherichia coli*. Journal of Bacteriology. 1999;181:5993–6002.

[49] Li M, Du X, Villaruz AE, Diep BA, Wang D, Song Y, Tian Y, Hu J, Yu F, Lu Y, Otto M. MRSA epidemic linked to a quickly spreading colonization and virulence determinant. Nature Medicine. 2012; 18:816–819.

[50] Miller MB, Bassler BL. Quorum sensing in bacteria. Annual Review of Microbiology. 2001; 55: 165–199.

[51] Annous BA, Fratamico PM, Smith JL. Quorum sensing in biofilms: why bacteria behave the way they do. Journal of Food Science. 2009. 74: 24–37.

[52] Atkinson S, Williams P. Quorum sensing and social networking in the microbial world. Journal of the Royal Society Interface. 2009; 6: 959–78.

[53] Yang L, Hu Y, Liu Y, Zhang J, Ulstrup J, Molin S. Distinct roles of extracellular polymeric substances in *Pseudomonas aeruginosa* biofilm development. Environmental Microbiology. 2011; 13: 1705–17.

[54] Yarwood JM, Bartels DJ, Volper EM, Greenberg EP Quorum sensing in *Staphylococcus aureus* biofilms. Journal of Bacteriology. 2004; 186:1838–50.

[55] Boles BR, Horswill AR. Agr-mediated dispersal of *Staphylococcus aureus* biofilms. PLOS Pathogens. 2008; **4**:e1000052.

[56] Branda SS, Gonzalez-Pastor JE, Ben-Yehuda S, Losick R, Kolter R Fruiting body formation by *Bacillus subtilis*. Proceedings of the National Academy of Sciences. 2001; 98:11621-6.

[57] Angelini TE, Roper M, Kolter R, Weitz DA, Brenner MP. *Bacillus subtilis* spreads by surfing on waves of surfactant. Proceedings of the National Academy of Sciences. 2009; 106: 18109–13.

[58] Davey ME, Caiazza NC, O'Toole GA.Rhamnolipid surfactant production affects biofilm architecture in *Pseudomonas aeruginosa* PAO1. Journal of Bacteriology. 2003; 185:1027–36.

[59] Boles BR, Thoendel M, Singh PK. Rhamnolipids mediate detachment of *Pseudomonas aeruginosa* from biofilms. Molecular Microbiology. 2005; 57:1210–1223.

[60] Wang R, Khan, B A, Cheung G Y, Bach TH, Jameson-Lee M, Kong K F, Queck SY, Otto M. *Staphylococcus epidermidis* surfactant peptides promote biofilm maturation and dissemination of biofilm-associated infection in mice. Journal of Clinical Investigation. 2011; 121:238–248.

[61] Lindsay D, Brözel VS, Mostert JF, von Holy A. Physiology of diary-associated *Bacillus* spp. over a wide pH range. International Journal of Food Microbiology. 2000; 54: 49–62.

[62] Liu Y, Tay JH. Detachment forces and their influence on the structure and metabolic behaviour of biofilms. World Journal of Microbiology and Biotechnology. 2001; 17: 111–17.

[63] Cabanes D, Dehoux P, Dussurget O, Frangeul L, Cossart P. Surface proteins and the pathogenic potential of *Listeria monocytogenes*. Trends Microbiology. 2002; 10: 238–45.

[64] Czaczyk K, Myszka K. Biosynthesis of extracellular polymeric substances (EPS) and its role in microbial biofilm formation. Polish Journal of Environmental Studies. 2007; 16: 799–806.

[65] Chia TW, Goulter RM, McMeekin T, Dykes GA, Fegan N. Attachment of different Salmonella serovars to materials commonly used in a poultry processing plant. Food Microbiology. 2009; 26(8): 853–9.

[66] Storgards E, Simola H, Sjoberg AM, Wirtanen G. Hygiene of gasket materials used in food processing equipment part 1: new materials. Food Bioproducts Process. 1999;77:137–45.

[67] Mariani C, Oulahal N, Chamba JF, Dubois-Brissonnet F, Notz E, Briandet R. Inhibition of *Listeria monocytogenes* by resident biofilms present on wooden shelves used for cheese ripening. Food Control. 2011; 22(8): 1357-62.

[68] Abdallah FB, Chaieb K, Zmantar T, Kallel H, Bakhrouf A. Adherence assays and slime production of *Vibrio alginolyticus* and *Vibrio parahaemolyticus*.Brazilian Journal of Microbiology. (2009). 394-8.

[69] Nilsson RE, Ross T, Bowman J P. Variability in biofilm production by *Listeria monocytogenes* correlated to strain origin and growth conditions. International Journal of Food Microbiology. 2011; 150(1): 14-24.

[70] Gerstel U, Römling U. Oxygen tension and nutrient starvation are major signals that regulate *agfD* promoter activity and expression of the multicellular morphotype in *Salmonella typhimurium*. Environmental Microbiology. 2001; 3(10): 638-648.

[71] Mcguire J, Swartzel K R. The influence of solid-surface energetics on macromolecular adsorption from milk. Journal of Food Processing and Preservation. 1989; 13(2): 145-60.

[72] Howell D, Behrends B, A review of surface roughness in antifouling coatings illustrating the importance of cut off length. Biofouling. 2006; 22: 401–410.

[73] Chaturongkasumrit Y, Takahashi H, Keeratipibul S, Kuda, T, Kimura B. The effect of polyester urethane belt surface roughness on *Listeria monocytogenes* biofilm formation and its cleaning efficiency. Food Control. 2011; 22:1893–1899.

[74] Hood SK, Zottola, EA. Biofilms in food processing. Food Control. 1995; 6: 9-18.

[75] Czaczyk K, Białas W, Myszka K, Cell surface hydrophobicity of *Bacillus* spp. as a function of nutrient supply and lipopeptides biosynthesis and its role in adhesion. Polish Journal of Microbiology. 2008; 57: 313–9.

[76] Faille C, Jullien C, Fontaine F, Bellon-Fontaine MN, Slomianny C, Benezech T. Adhesion of *Bacillus* spores and *Escherichia coli* cells to inert surface: role of surface hydrophobicity. Canadian Journal of Microbiology. 2002; 48: 728–38.

[77] Benito Y, Pin C, Marin ML, Garcia ML, Selgas MD, Casas C. Cell surface hydrophobicity and attachment of pathogenic and spoilage bacteria to meat surfaces. Meat Science. 1997; 45: 419–25.

[78] Flint SH, Brooks JD, Bremer PJ. The influence of cell surface properties of thermophilic streptococci on attachment to stainless steel. Journal of Applied Microbiology. 1997; 83: 508–17.

[79] Cunliffe D, Smart CA, Alexander C, Vulfson EN. Bacterial adhesion at synthetic surfaces. Applied Environmental Microbiology. 1999; 65: 4995–5002.

[80] Fuster-Valls N, Hernández-Herrero M, Marín-de-Mateo M, Rodríguez-Jerez JJ, Effect of different environmental conditions on the bacteria survival on stainless steel surface. Food Control. 2008; 19: 308–314.

[81] Baker JH. Factors affecting the bacterial colonization of various surfaces in a river. Canadian Journal of Microbiology, 1984; 30(4): 511-5.

[82] Sinde E, Carballo J. Attachment of *Salmonella* spp. and *Listeria monocytogenes* to stainless steel, rubber and polytetrafluorethylene: the influence of free energy and the effect of commercial sanitizers. Food Microbiology. 2000; 17: 439-447.

[83] Stepanovic S, Cirkovic I, Ranin L, Svabic-Vlahovic M. Biofilm formation by *Salmonella* spp. and *Listeria monocytogenes* on plastic surface. Letters in Applied Microbiology. 2004; .38: 428-32.

[84] Gudbjornsdottir B., Einarsson H., Thorkelsson G. Microbial adhesion to processing lines for fish fillets and cooked shrimp: Influence of stainless steel surface finish and presence of Gram-negative bacteria on the attachment of *Listeria monocytogenes*. Food Technology and Biotechnology. 2005; 43: 55–61.

[85] Thelin KH, Taylor RK. Toxin-coregulated pilus, but not mannose-sensitive hemagglutinin, is required for colonization by *Vibrio cholerae* O1 El Tor biotype and O139 strains. Infection and Immunity. 1996;64:2853–56.

[86] O'Toole GA, Kolter R. Flagellar and twitching motility are necessary for *Pseudomonas aeruginosa* biofilm development. Molecular Microbiology. 1998;30:295–304.

[87] Watnick PI, Kolter R. Steps in the development of a *Vibrio cholerae* biofilm. Molecular Microbiology. 1999;34:586–595.

[88] Jackson DW, Suzuki K, Oakford L, Simecka JW, Hart ME, Romeo T. Biofilm formation and dispersal under the influence of the global regulator CsrA of *Escherichia coli*. *Journal of Bacteriology.* 2002; **184:** 290–301.

[89] Farfan MJ, Torres AG. Molecular mechanisms that mediate colonization of Shiga toxin-producing *Escherichia coli* strains. Infection Immunity. 2012; 80:903- 13.

[90] Sutherland IW, Biofilm exopolysaccharides: a strong and sticky framework. Microbiology, 2001; 147: 3–9.

[91] Shu CH, Lung MY. Effect of pH on the production and molecular weight distribution of exopolysaccharide by *Antrodia camphorate* in batch cultures. Process Biochemistry. 2004; 39: 931–7.

[92] Czaczyk K, Białas W, Myszka K. Cell surface hydrophobicity of *Bacillus* spp. as a function of nutrient supply and lipopeptides biosynthesis and its role in adhesion. Polish Journal of Microbiology. 2008; 57: 313–9.

[93] Myszka K, Czaczyk K. Characterization of adhesive exopolysaccharide (EPS) produced by *Pseudomonas aeruginosa* under starvation conditions. Current Microbiology. 2009; 58: 541–6.

[94] Leriche V, Sibille P, Carpentier B. Use of an enzyme-linked lectinsorbent assay to monitor the shift in polysaccharide composition in bacterial biofilms. Applied Environmental Microbiology. 2000; 66:1851–6.

[95] Donian RM, Biofilms: microbial life on surfaces. Emerging Infectious Disease. 2002; 8: 881–90.

[96] Myszka K, Czaczyk K, Schmidt MT, Olejnik AM. Cell surface properties as factors involved in *Proteus vulgaris* adhesion to stainless steel under starvation conditions. World Journal of Microbiology and Biotechnology. 2007; 23: 1605–12.

[97] Sanin SL, Sanin FD, Bryers JD. Effect of starvation on the adhesive properties of xenobiotic degrading bacteria. Process Biochemistry. 2003; 38: 909–14.

[98] Herald PJ, Zottola EA. Scanning electron microscopic examination of *Yersinia enterocolitica* attached to stainless steel at elevated temperature and pH value. Journal of Food Science. 1988; 51: 445–8.

[99] Busalmen JP, de Sanchez SR, Influence of pH and ionic strength on adhesion of a wild strain of *Pseudomonas* sp. to titanium. Journal of Industrial Microbiology and Biotechnology. 2001; 26: 303–8.

[100] Fletcher M. The applications of interference reflection microscopy to the study of bacterial adhesion to solid surfaces. In: Houghton DR, Smith RN, Eggins HOW, editors. Biodeterioration 7. London: Elsevier Applied Science; 1988. p. 31–5.

[101] Fletcher M. Attachment of *Pseudomonas fluorescens* to glass and influence of electrolytes on bacterium-substratum separation distance. Journal of Bacteriology. 1988;170:2027–30.

[102] Barnes LM, Lo MF, Adams MR, Chamberlain AHL. Effect of milk proteins on adhesion of bacteria to stainless steel surfaces. Applied and Environmental Microbiology. 1999; 65: 4543–48.

[103] Giaouris E, Chorianopoulos N, Nychas, GJE Effect of temperature, pH and water activity on biofilm formation by *Salmonella enterica* Enteritidis PT4 on stainless steel surfaces, as indicated by bead vortexing method and by conductance measurements. Journal of Food Protection. 2005; 68: 2149–54.

[104] Kusumaningrum HD, Riboldi G, Hazeleger WC, Beumer R R Survival of foodborne pathogens on stainless steel surfaces and cross-contamination to foods. International Journal of Food Microbiology. 2003; 85: 227-36.

[105] Lee Wong AC. Biofilms in Food Processing Environments, Journal of Dairy Science. 1998; 81:2765-70.

[106] Carpentier B, Chassaing D. Interactions in biofilms between *Listeria monocytogenes* and resident microorganisms from food industry premises. International Journal of Food Microbiology. 2004; 97:111- 122.

[107] Ryu, Jee-Hoon, Beuchat, LR. Biofilm formation and sporulation by *Bacillus cereus* on stainless steel surface and subsequent resistance of vegetative cells and spores to chlorine, chlorine dioxide, and a peroxyacetic acid-based sanitizer. Journal of Food Protection. 2005; 68(12): 2614-22.

[108] Elhariry HM. Biofilm formation by endospore-forming bacilli on plastic surface under some food-related and environmental stress conditions. Global Journal of Biotechnology and Biochemistry. 2008; 3 (2): 69-78.

[109] Pan Y, Breidt F, Kathariou S. Competition of *Listeria monocytogenes* serotype 1/2a and 4b strains in mixed-culture biofilms. Applied and Environmental Microbiology. 2009; 75(18): 5846–52.

[110] Habimana, O, Heir E, Langsrud S, Asli AW, Møretrø T. Enhanced surface colonization by *Escherichia coli* O157:H7 in biofilms formed by an *Acinetobacter calcoaceticus* isolate from meat-processing environments. Applied and Environmental Microbiology. 2010; 76(13): 4557–59.

[111] Moons P, Michiels CW, Aertsen A. Bacterial interactions in biofilms. Critical Reviews in Microbiology. 2009; 35(3): 157–168.

[112] Nadell CD, Xavier J B, Foster KR. The sociobiology of biofilms. FEMS Microbiology Reviews. 2009; 33(1): 206–24.

[113] Rieu A, Lemaître JP, Guzzo J, Piveteau P. Interactions in dual species biofilms between *Listeria monocytogenes* EGD-e and several strains of *Staphylococcus aureus*. International Journal of Food Microbiology. 2008; 126(1–2): 76–82.

[114] Remis JP, Costerton JW, Auer M. Biofilms: Structures that may facilitate cell–cell interactions. The ISME Journal. 2010; 4(9): 1085–87.

[115] Uhlich GA, Rogers DP, Mosier D A. *Escherichia coli* serotype O157:H7 retention on solid surfaces and peroxide resistance is enhanced by dual-strain biofilm formation. Foodborne Pathogens and Disease, 2010; 7(8): 935–943.

[116] van der Veen S, Abee T. Mixed species biofilms of *Listeria monocytogenes* and *Lactobacillus plantarum* show enhanced resistance to benzalkonium chloride and peracetic acid. International Journal of Food Microbiology. 2011; 144(3): 421–31.

[117] Kostaki M, Chorianopoulos N, Braxou E, Nychas GJ, Giaouris E. Differential biofilm formation and chemical disinfection resistance of sessile cells of *Listeria monocytogenes* strains under monospecies and dual-species (with *Salmonella enterica*) conditions. Applied and Environmental Microbiology. 2012; 78(8): 2586–95.

[118] González Ribas F. Desarrollo y aplicación de sensores para evaluar la contaminación microbiológica de superficies domésticas españolas y de la efectividad de desinfectantes in situ de productos limpiadores comerciales. 2005.

[119] Cheng Y, Siletzky R, Kathariou S. Genomic division/lineages, epidemic clones and population structure. In: Dongyou, L. (Ed.), Handbook of *Listeria monocytogenes*. 2008; CRC Press, Boca Raton, pp. 337–57.

[120] Allerberger F, Wagner M. Listeriosis: a resurgent foodborne infection. Clinical Microbiology and Infection. 2010; 16: 16–23.

[121] Blackman IC, Frank JF. Growth of *Listeria monocytogenes* as a biofilm on various food-processing surfaces. Journal of Food Protection. 1996; 59: 827-31.

[122] Kathariou S. *Listeria monocytogenes* virulence and pathogenicity, a food safety perspective. Journal of Food Protection. 2002; 65: 1811-29.

[123] Giotis E, Mudcharee J, Wilkinson B, Blair I, McDowell D. Role of Sigma B factor in the alkaline tolerance of *Listeria monocytogenes* 10403S and cross protection against subsequent ethanol and osmotic stress. Journal of Food Protection. 2008; 71: 1481 – 5.

[124] Borucki MK, Peppin JD, White D, Loge F, Call DR. Variation in biofilm formation among strains of *Listeria monocytogenes*. Applied and Environmental Microbiology. 2003; 69: 7336-42.

[125] Moretro T, Langsrud S. *Listeria monocytogenes*: biofilm formation and persistence in food-processing environments. Biofilms. 2004; 1: 107-21.

[126] Moltz AG, Martin SE. Formation of biofilms by *Listeria monocytogenes* under various growth conditions. Journal of Food Protection. 2005; 68: 92-97.

[127] Ryser ET, Marth EH. *Listeria*, Listeriosis and Food Safety. 3rd Edn., CRC Press, Inc. New York. 2007. pp: 873.

[128] Di Bonaventura G, Piccolomini R, Paludi D, D'Orio V, Vergara A, Conter M, Ianieri A. Influence of temperature on biofilm formation by *Listeria monocytogenes* on various food-contact surfaces: relationship with motility and cell surface hydrophobicity. Journal of Applied Microbiology. 2008; 104: 1552–61.

[129] González Ribas F. Desarrollo y aplicación de sensores para evaluar la contaminación microbiológica de superficies domésticas españolas y de la efectividad de desinfectantes in situ de productos limpiadores comerciales. 2005.

[130] Keskinen LA, Todd ECD, Ryser E. Transfer of surface dried *Listeria monocytogenes* from stainless steel knife blades to roast turkey breast. Journal of Food Protection. 2008; 71: pp: 176-81.

[131] Duguid JP, Anderson ES, Campbell I. Fimbriae and adhesive properties in Salmonellae. Journal of Pathology and Bacteriology. 1966; 92: 107.

[132] Joseph B, Otta SK, Karunasagar I, Karunasagar I. Biofilm formation by *Salmonella* spp. on food contact surfaces and their sensitivity to sanitizers. International Journal of Food Microbiology. 2001; 64: pp: 367-372.

[133] Chmielewsky RAN, Frank JF. Biofilm formation and control in food processing facilities. Comprehensive Reviews in Food Science and Food Safety. 2003; 2: pp: 22-32.

[134] Houdt RV, Michiels CW. Role of bacterial cell surface structures in *Escherichia coli* biofilm formation. *Research in Microbiology.* 2005; 156: pp: 626-33.

[135] Lasa I. Towards the identification of the common features of bacterial biofilm development. International Microbiology. 2006; 9: 21-8

[136] Ternstrom A, Lindberg AM, Molin G. Classifcation of the spoilage flora of raw and pasteurised bovine milk, with special reference to *Pseudomonas* and *Bacillus.* Journal of Applied Bacteriology. 1993; 75: 25-34.

[137] Dogan B, Boor KJ. Genetic diversity and spoilage potentials among *Pseudomonas* spp. isolated from fluid milk products and dairy processing plants. Applied and Environmental Microbiology. 2003; .69:130-138.

[138] Read RR, Costerton JW. Purification and characterization of adhesive exopolysaccharides from Pseudomonas putida and *Pseudomonas fluorescens.* Canadian Journal of Microbiology. 1987; 3 (12):1080-90.

[139] Flint SH, Bremer PJ, Brooks JD. Biofilms in dairy manufacturing plant. Description, current concerns and methods of control. Biofouling. 1997; 11: 81-97.

[140] Gunduz GT, Tuncel G.Biofilm formation in an ice cream plant. International Journal of General and Molecular Microbiology. 2006; 89: 329-36.

[141] Storgards E, Tapani K, Hartwall P, Saleva R, Suihko ML. Microbial attachment and biofilm formation in brewery bottling plants. Journal of American Society of Brewing Chemistry. 2006; 64: 8-15.

[142] Sharma M, Anand SK. Characterization of constitutive microflora of biofilms in dairy processing lines. Food Microbiology. 2002;19: 627-36.

[143] Beuchat LR, Adler BB, Lang MM. Efficacy of chlorine and a peroxyacetic acid sanitizer in killing *Listeria monocytogenes* on iceberg and romaine lettuce using simulated commercial processing conditions. Journal of Food Protection. 2004; 67: 1238–42.

[144] Srey S, Jahid IK, Ha SD. Biofilm formation in food industries: A food safety concern. Food Control. 2012;31:572–85.

[145] Schmidt RH. Basic elements of equipment cleaning and sanitizing in food processing and handling operations. 2009; http://edis.ifas.ufl.edu/fs077 (accessed October 5, 2012).

[146] Betts G, Everis L. Alternatives to hypochlorite washing systems for the decontamination of fresh fruit and vegetables. In: Jongen, W. (Ed.), Improving the Safety of Fresh Fruit and Vegetables. , Wageningen, The Netherlands. 2005.

[147] Evans, D.A. Disinfectants. Wiley Encyclopedia of Food Science and Technology. 2000; 1: 501-9.

[148] *Marquand*, *EC*, Kacel M, Milhe F, Magnan A, Lehucher-Michel M. Asthma Caused by Peracetic Acid-Hydrogen Peroxide Mixture. *Journal of Occuational. Health.* 2007; 49 (2): 155–158.

[149] Kitis MD. Disinfection of wastewater with peracetic acid: a review. Environment International. 2004; 30: 47-55.

[150] Langsrud S, Sundheim G. Factors contributing to the survival of poultry associated *Pseudomonas* spp. Exposed to a quaternary ammonium compound. Journal of Applied Microbiology.1997; 82: 705-12.

[151] Sundheim G, Langsrud S, Heir E, Holck AL. Bacterial resistance to disinfectants containing quaternary ammonium compounds. International Biodeterrioration & Biodegradation. 1998; 41: 235-39.

[152] Langsrud S, Sundheim G, Borgmann-Strahsen R. Intrinsic and acquired resistance to quaternary ammonium compounds in food-related *Pseudomonas* spp. Journal of Applied Microbiology. 2003; 95: 874-82.

[153] Houari A, Di Martino P. Effect of chlorhexidine and benzalkonium chloride on bacterial biofilm formation. Letters in Applied Microbiology. 2007; 45: 652–56.

[154] Hou S, Liu Z, Young AW, Mark SL, Kallenbach NR, Ren D. Effects of Trp- and Arg-containing antimicrobial-peptide structure on inhibition of *Escherichia coli* planktonic growth and biofilm formation. Applied and Environmental Microbiology. 2010; 76: 1967–74.

[155] Marouani-Gadri N, Chassaing D, Carpentier B. Comparative evaluation of biofilm formation and tolerance to a chemical shock of pathogenic and nonpathogenic *Escherichia coli*O157:H7 strains. Journal of Food Protection. 2009; 72: 157–64.

[156] Wang R, Bono JL, Kalchayanand N, Shackelford S, Harhay DM. Biofilm formation by Shiga toxin-producing *Escherichia coli* O157:H7 and Non-O157 strains and their tolerance to sanitizers commonly used in the food processing environment. Journal of Food Protection. 2012; 75: 1418–28.

[157] Simões M, Simões LC, Vieira MJ. A review of current and emergent biofilm control strategies. LWT-Food Science and Technology. 2010; 43: 573-83.

[158] Chorianopoulos NG, Giaouris ED, Skandamis PN, Haroutounian SA, Nychas, GJE. Disinfectant test against monoculture and mixed-culture biofilms composed of technological, spoilage and pathogenic bacteria: bactericidal effect of essential oil and hydrosol of *Satureja thymbra* and comparison with standard acid based sanitizers. Journal of Applied Microbiology. 2008; 104: 1586-96.

[159] Knowles JR, Roller S, Murray DB, Naidu AS. Antimicrobial action of carvacrol at different stages of dual-species biofilm development by *Staphylococcus aureus* and *Salmonella enterica* Serovar Typhimurium. Applied and Environmental Microbiology. 2005; 7(12): 797-803.

[160] Leonard CM, Virijevic S, Regnier T, Combrinck S. Bioactivity of selected essential oils and some components on *Listeria monocytogenes* biofilms. South African Journal of Botany. 2010; 76: 676-80.

[161] Valeriano C, Piccoli RH, Cardoso MG, Alves E. Antimicrobial activity of essential oils against sessile and planktonic pathogens of food source. Revista Brasileira de Plantas Medicinais. 2012; 14: 57-67.

[162] Giaouris E, Heir E, Hébraud M, Chorianopoulos N, Langsrud S, Møretrø T, Habimana O, Desvaux M, Renier S, Nychas GJ. Attachment and biofilm formation by foodborne bacteria in meat processing environments: causes, implications, role of bacterial interactions and control by alternative novel methods. Meat Science. 2014; 97: 298–309.

[163] Sandasi M, Leonard CM, Viljoen AM. The in vitro antibiofilm activity of selected culinary herbs and medicinal plants against *Listeria monocytogenes*. Letters in Applied Microbiology. 2010; 50: 30-35.

[164] Rendueles O, Kaplan JB, Ghigo JM. Antibiofilm polysaccharides. Environmental Microbiology. 2012;15:334-46.

[165] Valle J, Da Re S, Henry N, Fontaine T, Balestrino D, Latour-Lambert P, Ghigo, J. Broad-spectrum biofilm inhibition by a secreted bacterial polysaccharide. Proceedings of the National Academy of Sciences. 2006; 103: 12558–563.

[166] Rendueles, O, Travier L, Latour-Lambert P, Fontaine T, Magnus J, Denamur E, Ghigo J. Screening of Escherichia coli species biodiversity reveals new biofilm associated anti adhesion polysaccharides. MBio.2011; 2: e00043–e00011.

[167] Lequette Y, Boels G, Clarisse M, Faille C. Using enzymes to remove biofilms of bacterial isolates sampled in the food-industry. Biofouling. 2010; 26: 421–31.

[168] Xavier JB, Picioreanu C, Rani SA, van Loosdrecht MC, Stewart PS. Biofilm-control strategies based on enzymatic disruption of the extracellular polymeric substance matrix–a modelling study. Microbiology. 2005; 151:3817–32.

[169] McDougald D, Rice SA, Barraud N, Steinberg PD, Kjelleberg S. Should we stay or should we go: mechanisms and ecological consequences for biofilm dispersal. National Reviews Microbiology. 2011; 10(1):39–50.

[170] Bower CK, Daeschel MA, McGuire J. Protein antimicrobial barriers to bacterial adhesion. *Journal of Dairy Science.* 1998; 81:2771-78.

[171] Delves-Broughton, J. Nisin and its application as a food preservative. Journal of the Society of Dairy Technology. 1990. 43**:**73-76.

[172] Abee T, Rombouts FM, Hugenholtz J, Guihard G, Letellier L. Mode of action of Nisin Z against *Listeria monocytogenes* Scott A grown at high and low temperatures. Applied and Environmental Microbiology. 1994; 60(6):1962-8.

[173] Dosler S, Mataraci E. In vitro pharmacokinetics of antimicrobial cationic peptides alone and in combination with antibiotics against methicillin resistant *Staphylococcus aureus* biofilms. Peptides. 2013;49:53-8.

[174] Okuda K, Zendo T, Sugimoto S, Iwase T, Tajima A, Yamada S, Sonomoto K, Mizunoe Y. Effects of bacteriocins on methicillin-resistant *Staphylococcus aureus* biofilm. Antimicrobial Agents and Chemotheraphy. 2013; 57(11):5572-9.

[175] de Nys R, Wright AD, Konig GM, Sticher O. New halogenated furanones from the marine alga *Delisea pulchra* (cf. fimbriata). Tetrahedron. 1993;49:11213-20.

[176] Janssens JC, Steenackers H, Robijns S, Gellens E, Levin J, Zhao H, Hermans K, De Coster D, Verhoeven TL, Marchal K, Vanderleyden J, De Vos DE, De Keersmaecker SC. Brominated furanones inhibit biofilm formation by Salmonella enterica serovar Typhimurium. Applied and Environmental Microbiology. 2008; 74: 6639– 48.

[177] Valle Gomes MZ, Nitschke M. Evaluation of rhamnolipid and surfactin to reduce the adhesion and remove biofilms of individual and mixed-species of food pathogenic bacteria. Food Control. 2012; 25:441–7.

[178] Quinn GA, Maloy AP, McClean S, Carney B, Slater JW. Lipopeptide biosurfactants from *Paenibacillus polymyxa* inhibit single and mixed species biofilms. Biofouling. 2012; 28(10):1151–66.

[179] Eswaranandam S, Hettiarachchy NS, Johnson MG. Antimicrobial activity of citric, lactic, malic, or tartaric acids and nisin-incorporated soy protein film against *Listeria monocytogenes*, *Escherichia coli* O157:H7, and *Salmonella gaminara*. Food Microbiology and Safety. 2004; 69(3):FMS79-FMS84.

[180] Akbas MY, Olmez H. Inactivation of *Escherichia coli* and *Listeria monocytogenes* on iceberg lettuce by dip wash treatments with organic acids. Letters in Applied Microbiology. 2007; 44: 619–24.

[181] Hsiao C, Siebert KJ. Modelling the inhibitory effects of organic acids on bacteria. International Journal of Food Microbiology. 1999; 47: 189-201.

[182] Ahn YS, Shin DH. Antimicrobial effects of organic acid and ethanol on several foodborne microorganisms. Korean Journal of Food Science and Technology. 1999; 31: 1315-23.

[183] Ricke SC Perspectives on the use of organic acids and short chain fatty acids as antimicrobials. Poultry Sciences. 2003; 82: 632–39.

[184] USDA-FSIS. Safe and suitable ingredients used in the production of meat and poultry products. 2010. Directive 7120.1.rev.2.www.isis.usda.gov.OPPD E /dad/FISIS directives/7120.1.Rev2.pdf Accessed January 11, 2011.

[185] Tsai YP, Pai Ty, Hsin JY, Wan TJ. Biofilm bacteria inactivation by citric acid and resuspension evaluations for drinking water production systems. Water Science and Systems. 2003; 48: (11-12) 463-72.

[186] Lieleg O, Caldaraa M, Baumgärtela R, Ribbeck K. Mechanical robustness of *Pseudomonas aeruginosa* biofilms. Soft Matter. 2011; 7 (7): 3307–14.

[187] Akbas MY, Kokumer T. The prevention and removal of biofilm formation of *Staphylococcus aureus* strains isolated from raw milk samples by citric acid treatments. International Journal of Food Science and Technology. 2015; 50 (7): 1666-72.

[188] Obreque-Slier E, Peña-Neira A, López-Solís R, Zamora-Marín F, Ricardo da Silva J, Laureano O. Comparative study of the phenolic composition of seeds and skins from Carménère and Cabernet Sauvignon grape varieties (*Vitis vinifera* L.) during ripening. Journal of Agricultural and Food Chemistry. 2010; 58: 3591-3599.

[189] Chanwitheesuk A, Teerawutgulrag A, Kilburn JD, Rakariyatham N. Antimicrobial gallic acid from Caesalpinia mimosoides Lamk Food Chemistry. 2007; 100(3): 1044-48.

[190] Borges A, Saavedra MJ, Simões M. The activity of ferulic and gallic acids in biofilm prevention and control of pathogenic bacteria. Biofouling, 2012; 28: 755-67.

[191] Samappito S, Butkhup L. An analysis on organic acids contents in ripe fruits of fifteen mao luang (*Antidesma bunius*) cultivars, harvested from dipterocarp forest of Phupan Valley in Northeast Thailand. Pakistan Journal of Biological Sciences. 2008; 11: 974-81.

[192] Anvoh KYB, Zoro Bi A, Gnakri D. Production and characterization of juice from mucilage of Cocoa beans and its transformation into marmalade. Pakistan Journal of Nutrition. 2009; 8: 129-33.

[193] Kossah R, Nsabimana C, Zhao JX, Chen HQ, Tian FW, Zhang H, Chen W. Comparative study on the chemical composition of Syrian sumac (*Rhus coriaria* L.) and Chinese sumac (*Rhus typhina* L.) fruits. Pakistan Journal of Nutrition. 2009; 8: 1570-74.

[194] Shirzadeh E, Kazemi M. Effect of malic acid and calcium treatments on quality characteristics of apple fruits during storage. American Journal of Plant Physiology. 2011; 6: 176-182.

[195] Nahar K, Ullah SM, Islam N. Osmotic adjustment and quality response of five tomato cultivars (*Lycopersicon esculentum* Mill) following water deficit stress under subtropical climate. Asian Journal of Plant Sciences. 2011; 10: 153-7.

[196] Beuchat LR, Golden DA. Antimicrobials occurring naturally in foods. Food Technology. 1989; 43: 134–42.

[197] Eswaranandam S, Hettiarachchy NS, Johnson MG. Antimicrobial activity of citric, lactic, malic, or tartaric acids and nisin-incorporated soy protein film against *Listeria monocytogenes*, *Escherichia coli* O157:H7 and *Salmonella gaminara.* Journal of Food Science, 2004; 69: 79–84.

[198] Singla R, Ganguli A. Novel synergistic approach to exploit the bactericidal efficacy of commercial disinfectants on the biofilms of *Salmonella enterica* serovar Typhimurium. Journal of Bioscience and Bioengineering. 2014; 118(1):34-40.

[199] Romero D, Kolter R. Will biofilm disassembly agents make it to market? Trends in Microbiology. 2011; 19: 304-6.