Surface modification of food processing and handling gloves for enhanced food safety and hygiene

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Abstract

Gloves made of materials such as latex, nitrile, and polyethylene are the most common types of barriers used to prevent cross-contamination and transmission of pathogenic bacteria in the food industry. In this study, we report a surface modification approach involving “fluorinated silica nanoparticles” (FSNs) to improve the barrier properties of disposable glove surfaces. The bacterial antiadhesive (antifouling) properties of the modified gloves were evaluated with *Salmonella* Typhimurium LT2 and *Staphylococcus aureus* at bacterial concentrations of 8.6 to 9.0 log CFU/mL through the dip-inoculation approach. Bacterial attachment to glove surfaces were enumerated by the pour plating method as well as direct counting via scanning electron microscopy (SEM). The bacterial populations of *S. Typhimurium* LT2 and *S. aureus* on FSN-coated latex, nitrile and polyethylene gloves was reduced by 1 to 2 log units in comparison to bare gloves.

Keywords: Food safety, Bacterial pathogen, Bacterial cross-contamination, Disposable gloves

1. Introduction

Foodborne illnesses are a global concern as they lead to morbidity and mortality with increasing rates throughout the world (Akhtar et al., 2014; Shi and Zhu, 2009). Bacterial pathogens such as *Salmonella* spp., *Escherichia coli*, *Campylobacter* spp., *Staphylococcus aureus*, *Listeria monocytogenes*, and *Bacillus cereus* are some of the major causes of foodborne illnesses (Kirk et al., 2015; Tauxe et al., 2010). According to the U.S. Centers for Disease Control and Prevention report 2013, bacterial pathogens account for 70.7% of all foodborne illnesses for meat and poultry, 43.8% for dairy and eggs, 42.0% for grains and beans, 24.1% for fish and shellfish, and 22.3% for produce (Painter et al., 2013). Bacterial pathogens can come into contact with food and food products at any stage of “food-preparation”, i.e., harvesting, slaughtering, processing, handling, and storage (DeVita et al., 2007; Todd et al., 2007). While there are various procedures for effective disinfecting of food-contact surfaces and reducing other bacterial contaminants (Azlin-Hasim et al., 2015; Chang and Schneider, 2012; Lavoine et al., 2014; Nguyen and Yuk, 2013; Sung et al., 2014; Surowsky et al., 2015; Zhang et al., 2015), such disinfection could be rescinded due to possible mishandled after cleaning and sanitizing. Hence, it is a common practice to use gloves to handle food and food products after sanitation processes (Todd et al., 2010). From a food safety perspective, gloves serve for two purposes: (i) to reduce the possibility of cross-contamination from food to food and (ii) to eliminate the possibility of transmission of pathogenic bacteria from human hands to food.

While the use of gloves improves food safety and hygiene, and is desired for food processing and handling (Green et al., 2007), gloves are not completely problem-free. For instance, when glove surfaces come into contact with bacterial pathogens, bacterial adhesion occurs and the bacteria can subsequently form biofilm on these surfaces (Chmielewski and Frank, 2003). If formed, bacterial biofilms are particularly difficult to eliminate using hygienic practices such as physical washing (e.g., brushing, scrubbing, and sonication) and chemical treatments (e.g., alcohol-based disinfectant, chlorine-based sanitizer, and hydrogen peroxide-based solution), because bacteria are embedded in their own extracellular polymeric substances, which guard bacteria against external physical forces and chemical agents attack (Corcoran et al., 2014). Along these lines, Kaneko et al. (1999) have reported the occurrence of bacterial retention on glove surfaces and the possibility of glove-facilitated bacterial transport. Kotwal et al. (2014) found that transfer of *Salmonella* from porcine skins to thick latex, thin latex, and nitrile gloves

can take place with the transfer rate of 40%, 27%, and 19%, respectively. Brar and Danyluk (2013) reported that *Salmonella* can transfer from disposable latex gloves to tomatoes with a transfer coefficient of 32% and 29% under wet and dry conditions, respectively, and from tomatoes to gloves with a transfer coefficient of 37% and 39% under wet and dry conditions, respectively. Overall, it is fair to claim that wearing gloves does not fully ensure the prevention of cross-contamination and transmission of pathogenic bacteria during food processing and handling.

To avoid the scenarios of cross-contamination and transmission of pathogenic bacteria through glove surfaces, research efforts have been undertaken, in particular, towards antimicrobial modifications of glove surfaces (Bastarrachea et al., 2015). Surface functionalization with antimicrobial agents have been shown to be capable of preventing the spread of pathogenic bacteria. For example, antimicrobial agent (i.e., polyhexanide) generating glove surfaces (Leitgeb et al., 2013), glove surfaces impregnated with antiseptic dye (i.e., chlorhexidine) (Reitzel et al., 2009), and active release of disinfectant (i.e., chlorine dioxide) from the glove surfaces upon stimulation with moisture or light (Barza, 2004) have recently been reported. However, while gloves bearing antimicrobial agents reduce the bacterial growth and improve food safety, there are several issues that still need to be overcome such as the ineffectiveness against antimicrobial-resistant bacteria (Rasko and Sperandio, 2010), the development of antimicrobial resistance due to continuous exposure to antimicrobial agents (Levy and Marshall, 2004), and the long-term antimicrobial inefficiency (Puckett et al., 2010).

An alternative approach in reducing cross-contamination and transmission of pathogenic bacteria is the development of bacteria-repellent and antiadhesive (antifouling) surfaces. These surfaces reduce the bacterial adhesion to the surface of interest or repel bacteria from the surface of interest (Fadeeva et al., 2011; Oh et al., 2016). In other words, the goal is to minimize the number of bacteria reaching/attaching to the surface rather than disinfect bacteria reaching/attaching to the surface. Some examples of above-mentioned approaches for food safety applications can be enumerated, such as bacteria-repellent polyethylene glycol-coated surfaces (Zhang et al., 2014), zwitterionic surfaces (Cheng et al., 2007), functional biomimetic surfaces (Bixler and Bhushan, 2014), nanoporous methylated surfaces (Oh et al., 2015), stimuli-responsive surfaces capable of surface deformation induced by shear forces (Shivapooja et al., 2013), and multilayer films containing heparin as an antiadhesive agent (Fu et al., 2005). While

there are a number of studies reporting applications of these modifications on common food-contact surfaces such as stainless steel (Yang et al., 2011), quartz glass (Oh et al., 2015), paper (Jin et al., 2012), polycarbonate (Ding et al., 2012), polytetrafluoroethylene (Epstein et al., 2012), and polyurethane (Park et al., 1998), the incorporation of gloves with bacterial antiadhesive properties have not been achieved yet.

Herein, we report the preparation of gloves with bacterial antiadhesive properties for food processing and handling applications using a scalable and facile dip-coating method. The coating has been applied on the three different types of gloves (i.e., latex, nitrile, and polyethylene) and achieved through the deposition and polymerization of “fluorinated silica nanoparticles” (FSNs) on glove surfaces. To evaluate the bacterial antiadhesive properties of the developed gloves, Gram-negative *S. Typhimurium* LT2 and Gram-positive *S. aureus* were utilized through an inoculation assay. The mechanical durability and chemical stability of FSN-coated gloves were investigated using scanning electron microscopy (SEM), nanotribometry, and attenuated total reflectance-Fourier transform infrared (ATR-FTIR) spectroscopy.

2. Material and Methods

2.1. Preparation of glove surfaces

Three different types of disposable gloves, i.e., latex (Polymed; Sempermed USA, Inc., Clearwater, FL, USA), nitrile (Upperhand; Maytex Co., Hayward, CA, USA), and polyethylene (Poly-D; Ansell, Richmond, Australia) commonly used glove materials for food processing and handling were prepared for the comparative studies. Gloves were first rinsed with Milli-Q water (resistivity ≥ 18.2 M Ω ·cm) produced by a Milli-Q water purification system (Milli-Q Advantage A10; EMD Millipore Corp., Billerica, MA, USA), and left to dry at room temperature (23 °C).

2.2. Fluorinated silica nanoparticles (FSNs)

100 mg of silica (SiO₂; Sigma-Aldrich Co., St. Louis, MO, USA) nanoparticles with average diameter of ~200 nm was suspended in 15 mL of hexane (Avantor Performance Materials, Inc., Center Valley, PA, USA), and then 5 mM of trichloro(1H,1H,2H,2H-perfluorooctyl)silane (FDTs; Sigma-Aldrich Co., St. Louis, MO, USA) was added to obtain “fluorinated silica nanoparticles” (FSNs). FSNs were homogeneously suspended under sonication for 20 min using a probe ultrasonicator (SJIA-2000W; Ningbo Haishu Sklon

Electronics Instruments Co., Ltd., Ningbo, Zhejiang, China). The FSN suspension was then left for 1 h to allow the silane to fully react with silica nanoparticles.

2.3. Dip-coating of glove surfaces

FSNs were deposited on glove surfaces by dip-coating method (Fig. 1). Latex, nitrile, and polyethylene gloves were first cut into 1 cm × 1 cm pieces. Gloves were then dipped into the FSN suspension. The method involved dipping gloves for 30 sec and then allowing gloves to dry for 30 sec five times over a 5-min period. FSN-coated gloves were then left to dry at room temperature for 24 h.

2.4. Surface characterization

Surface morphology of glove surfaces were examined by scanning electron microscope (SEM, JSM-7500F; JEOL, Tokyo, Japan). Before SEM examination, the samples were coated with 8 nm of platinum/palladium (Pt/Pd) to minimize possible charging effects. The SEM was operated at an accelerating voltage of 1 kV and emission current of 20 μA.

Topographic characteristics of glove surfaces were investigated by Dektak 3 stylus profilometer (Veeco Instruments, Inc., Plainview, NY, USA) with a scan length of 100 μm to obtain surface roughness values. The samples were mounted on a glass slide by using a double-sided tape and then placed onto the stage to decrease data noise.

The chemical interactions between glove surfaces and FDTs-functionalized silica nanoparticles were characterized by attenuated total reflectance-Fourier transform infrared (ATR-FTIR) spectroscopy technique. ATR-FTIR spectra were measured using IRPrestige-21 (Shimadzu Corp., Kyoto, Japan) system and analyzed using IRsolution version 1.40 software (Shimadzu Corp., Kyoto, Japan).

In order to determine the wetting characteristics of glove surfaces, the static water contact angles were measured for the three different types of glove surfaces using the sessile drop technique. Reported contact angles on each surface were obtained by averaging five measurements at room temperature with the same droplet volume (5 μL). Contact angles were analyzed using ImageJ software (National Institutes of Health, Bethesda, MD, USA) via Low-Bond Axisymmetric Drop Shape Analysis (LBADSA) plug-in (Stalder et al., 2010).

2.5. Bacterial cultures

Working cultures of *Salmonella enterica* subsp. *enterica* serovar Typhimurium str. LT2 (ATCC 700720) and *Staphylococcus aureus* (Food Microbiology Laboratory, Department of Animal Science, Texas A&M University, College Station, TX) were obtained by scraping a portion of a culture on a tryptic soy agar (TSA; Becton, Dickinson and Co., Sparks, MD, USA) slant, and transferring to 9 mL of tryptic soy broth (TSB; Becton, Dickinson and Co., Sparks, MD, USA). These bacterial cultures were incubated aerobically without agitation at 37 °C for 24 h. After 24 h, a loopful of culture was transferred to fresh TSB, and reincubated at 37 °C for 24 h twice consecutively. The final concentrations reached by *S. Typhimurium* LT2 and *S. aureus* in the growth medium ranged from 8.6 to 9.0 log CFU/mL.

2.6. Surface inoculation

For inoculation, bare and FSN-coated gloves were submerged in 9 mL of a bacterial suspension (8.6–9.0 log CFU/mL) at room temperature for 1h and 24 h. The samples were gently removed from the bacterial suspension in a single vertical motion. After, the samples were rinsed in sterile Milli-Q water (10 mL) to dislodge loosely attached cells, and then transferred to sterile Petri dish for further bacterial adhesion assay. Bacteria that were not removed by Milli-Q water rinse were assumed to be attached. All experiments were carried out in an appropriate biological safety cabinet under sterile conditions. Inoculation experiments were replicated four times.

2.7. Bacterial adhesion assay

Bacterial attachment on glove surfaces with and without surface modification was assessed by plate count using the pour plating method and by direct enumeration on glove surfaces using SEM. For plate counts, gloves that were dip-inoculated for 1 h were vortex-mixed in 0.1% (w/v) peptone water for 10 min to detach bacteria from the glove surfaces. After, serial dilutions of peptone water containing detached bacteria were made and plated on TSA plate. Bacterial densities were determined after 24 h of aerobic incubation at 37 °C and represented the density of bacteria that were attached onto the glove surfaces. All experiments were replicated four times.

The direct enumeration of attached bacteria on glove surfaces using SEM was conducted on gloves that were dipped in the inoculum for 1 h and 24 h. Prior to SEM imaging, bacteria were inactivated by acrolein (Sigma-Aldrich Co., St. Louis, MO, USA) and a thin layer (10 nm) of

Pt/Pd film was deposited on the sample surfaces to ensure the electrical conductivity required by SEM technique. For statistical reliability, at least ten different areas of $100\ \mu\text{m} \times 100\ \mu\text{m}$ (i.e., entire scan area larger than $100,000\ \mu\text{m}^2$) from the three different samples of the same type of glove surface were observed. As a direct counting approach, SEM micrographs were analyzed using ImageJ to quantify the attachment of *S. Typhimurium* LT2 and *S. aureus* to glove surfaces.

2.8. Mechanical robustness and chemical stability of glove coating

Shear strength of glove coating was investigated using a nanotribometer (NTR; Anton Paar TriTec SA, Peseux, Switzerland). Produce-attached tip was used in the measurements. To prepare produce-attached tip, a spinach leaf cut into $3\ \text{mm} \times 3\ \text{mm}$ piece was attached to the tip by using an instant glue. All tests were conducted using a cantilever spring with normal and tangential stiffness of $55.9\ \text{N/m}$ and $36.8\ \text{N/m}$, respectively, at normal load of $10\ \text{mN}$, which provides a pressure of $\sim 5,000\ \text{N/m}^2$. These experimental conditions were chosen based on a previous report suggesting grip force for common produce, e.g., strawberry ($\sim 1,300\ \text{N/m}^2$), carrot ($\sim 4,300\ \text{N/m}^2$), and apple ($\sim 5,000\ \text{N/m}^2$) (Pettersson et al., 2011). Before and after shearing experiments, the presence of wear and surface damage were investigated by SEM examination as well as measuring surface roughness of FSN-coated gloves using a profilometer.

Chemical stability of FSN-coated gloves was determined in deionized (DI) water as a function of time by monitoring if there is any chemical leaching from FSN-coated glove surfaces. This was achieved through analyzing aliquots collected from the samples (i.e., FSN-coated glove pieces submerged in DI water) using ATR-FTIR spectroscopy, with detection limit of $<1\ \text{ppm}$. While average time of wearing disposable glove is usually less than $4\ \text{h}$, the measurements were conducted at submersion time of $24\ \text{h}$, which present a sufficient condition.

2.9. Statistical analysis

The microbiological data were log-transformed prior to the statistical analysis. One-way and two-way analysis of variance (ANOVA) with Tukey's post hoc test was used to determine whether there were significant differences in the microbiological data between types of glove surfaces and types of bacteria, at a significance level of 0.05 . All statistical analyses were performed using Analysis ToolPak–Excel (Microsoft Corp., Redmond, WA, USA) via statistical packages.

3. Results and discussion

3.1. Characterization of FSN-coated glove surfaces

Previous studies have shown that nano-scale and micro-scale surface roughness can influence bacterial adhesion (Cañas et al., 2012; Truong et al., 2010). When the length scale of surface roughness is larger than bacterial size, bacterial colonization can be enhanced because bacteria prefer to attach to concave surfaces (e.g., valleys, pits, edges, and depressions) due to increase in bacteria-surface total contact area (Wu et al., 2011). Hence, we characterized the surface topography of glove surfaces used in this study to better understand their bacterial adhesion behavior. SEM micrographs visually reveal nanostructures covering FSN-coated latex, nitrile, and polyethylene glove surfaces without interstices, as shown in Figs. 2a-c. To quantitatively compare the dimensional characteristics of bacterial size and surface roughness of gloves, the profilometer measurements were performed. The surface metrology measurements of FSN-coated latex, nitrile, and polyethylene gloves showed that the root-mean-square (RMS) roughness were 419 ± 34 nm, 406 ± 28 nm, and 395 ± 40 nm, respectively. This means that surface roughness length scales of FSN-coated gloves were smaller than bacterial size (e.g., rod-shaped *S. Typhimurium* LT2 is 700–1500 nm wide by 2000–5000 nm long and spherical-shaped *S. aureus* is 600–1000 nm in diameter), thereby inhibiting the physical attachment such as penetration and trapping of bacteria into FSN-coated glove surfaces. Moreover, surface roughness of FSN-coated gloves meets the specific surface roughness value (≤ 800 nm) for proper hygienic design criteria for food-contact surfaces (Flint et al., 2000).

For the chemical modification of glove surfaces, fluorinated silane compound is selected due to its high affinity to silica (Vansant et al., 1995). Also, trifluoromethyl ($-\text{CF}_3$) functional groups are preferred over other nonpolar functional groups, because surface energy (γ) decreases as hydrogen (H) atoms are replaced with fluorine (F) atoms in the following orders: $-\text{CH}_2 > -\text{CH}_3 > -\text{CF}_2 > -\text{CF}_2\text{H} > -\text{CF}_3$ (Hare et al., 1954). While bacteria can adhere on both hydrophilic and hydrophobic surfaces, it is known that bacterial attachment tends to occur significantly more on hydrophilic surfaces (Boks et al., 2008). Hence, we used trifluoromethyl functional groups to coat glove surfaces in order to reduce the intermolecular interactions between bacteria and surfaces. The presence of trifluoromethyl groups on glove surfaces was confirmed by ATR-FTIR spectroscopy analysis for all three different types of gloves (Fig. 3). To be specific, there was a

peak at $\sim 1050\text{ cm}^{-1}$, corresponding to C-F stretching (Zeitler and Brown, 1957), for each glove surface upon dip-coating.

Surface topography and chemical properties can act synergistically and influence the ability of water dispersing bacteria to come in contact with surfaces in a non-linear fashion by creating air-pockets (Lorenzetti et al., 2015). As such, we also studied the wetting characteristics of gloves surfaces with water. Figs. 3b-g compare the contact angle of water droplets on bare and FSN-coated glove surfaces. The static water contact angle measurements revealed that bare latex ($\theta = 126.7^\circ \pm 1.4^\circ$), nitrile ($\theta = 97.2^\circ \pm 0.4^\circ$), and polyethylene ($\theta = 90.9^\circ \pm 0.5^\circ$) gloves were hydrophobic. On the other hand, their FSN-coated versions were superhydrophobic with a contact angle of $\theta = 162.5^\circ \pm 0.7^\circ$ (latex), $\theta = 162.7^\circ \pm 1.1^\circ$ (nitrile), and $\theta = 163.9^\circ \pm 0.6^\circ$ (polyethylene). Superhydrophobic surfaces are well-known as having self-cleaning properties (often termed the “lotus effect”), which is beneficial for reducing bacterial adhesion (Fürstner et al., 2005; Zhang et al., 2013).

3.2. Bacterial attachment to FSN-coated glove surfaces characterized by plating counting

After preparing and fully characterizing interfacial properties of the modified glove surfaces, we compared the bacterial attachment behavior on such surfaces with that on bare glove surfaces. Fig. 4a shows the plate count results of the three different types of gloves, following inoculation and attachment of Gram-negative *S. Typhimurium* LT2. The mean populations of bacteria attached on bare latex, nitrile, and polyethylene glove surfaces were $5.3 \pm 0.1\text{ log CFU/mL}$, $5.3 \pm 0.1\text{ log CFU/mL}$, and $5.1 \pm 0.1\text{ log CFU/mL}$, respectively, indicating that these surfaces supported bacterial attachment. When latex, nitrile, and polyethylene gloves were modified with FSNs to achieve a superhydrophobic character, bacterial attachment decreased, as indicated by the mean bacterial populations of $3.4 \pm 0.2\text{ log CFU/mL}$, $3.4 \pm 0.1\text{ log CFU/mL}$, and $3.3 \pm 0.1\text{ log CFU/mL}$, respectively, corresponding to $>98.2\%$ in bacterial attachment. One-way ANOVA analysis showed the difference in the adhesion of *S. Typhimurium* LT2 with respect to the presence or absence of coating was statistically significant ($p < 0.05$).

The above observed trends also took place for Gram-positive bacteria, as observed in the plating experiments using *S. aureus*. Fig. 4b graph shows the plate count results of *S. aureus* attachment on the three different types of gloves. Bare latex, nitrile, and polyethylene glove surfaces yielded mean densities of $5.5 \pm 0.1\text{ log CFU/mL}$, $5.4 \pm 0.1\text{ log CFU/mL}$, and 5.3 ± 0.1

log CFU/mL, respectively. In contrast, superhydrophobic FSN-coated latex, nitrile, and polyethylene gloves had a reduced the number of bacteria, with mean densities of 3.5 ± 0.2 log CFU/mL, 3.5 ± 0.2 log CFU/mL, and 3.2 ± 0.2 log CFU/mL, respectively, which corresponds to >98.5% reduction. According to one-way ANOVA analysis, the difference in the number of *S. aureus* with respect to the presence or absence of coating was statistically significant ($p < 0.05$). Overall, plating studies showed that the number of *S. Typhimurium* LT2 and *S. aureus* with the use of FSN coating on gloves decreased by 1 to 2 log CFU/mL on them. The comparison of microbiological data on the three different types of glove surfaces with respect to types of bacteria via two-way ANOVA analysis indicated that the attachment behavior of *S. Typhimurium* LT2 and *S. aureus* to glove surfaces were not statistically significant ($p \geq 0.05$), indicating a similar reduction behavior for all types of gloves upon FSN coating.

3.3. Bacterial attachment to FSN-coated glove surfaces characterized by SEM

In addition to the pour plating method, SEM was also used to enumerate bacteria on glove surfaces to gain insight into the distribution and localization of bacteria on these surfaces. Fig. 5 shows the SEM micrographs of *S. Typhimurium* LT2 attached on the three different types of glove surfaces upon 1 h and 24 h inoculation. After 1 h exposure to bacteria, bacterial attachment to bare latex, nitrile, and polyethylene gloves resulted in mean densities of 4.1 ± 0.2 log cells/mm², 4.0 ± 0.2 log cells/mm², and 4.0 ± 0.1 log cells/mm², respectively (Figs. 5a-c). Inoculation of FSN-coated latex, nitrile, and polyethylene gloves resulted in mean densities of 2.3 ± 0.1 log cells/mm², 2.2 ± 0.0 log cells/mm², and 2.3 ± 0.2 log cells/mm², respectively. (Figs. 5d-f), which corresponds to >97.7% reduction in bacterial attachment in comparison to bare gloves. After 24 h exposure to bacteria, bacterial attachment to bare latex, nitrile, and polyethylene gloves resulted in mean densities of 4.9 ± 0.1 log cells/mm², 5.1 ± 0.1 log cells/mm², and 5.0 ± 0.0 log cells/mm², respectively (Figs. 5g-i). Inoculation of FSN-coated latex, nitrile, and polyethylene gloves resulted in mean densities of 2.7 ± 0.2 log cells/mm², 2.6 ± 0.2 log cells/mm², and 2.6 ± 0.2 log cells/mm², respectively. (Figs. 5j-l), which corresponds to >99.3% reduction in bacterial attachment in comparison to bare gloves. In essence, bacterial attachment to superhydrophobic FSN-coated gloves was much less than bare gloves, with reduced the number of *S. Typhimurium* LT2 by 1 to 2 log units.

We also enumerated the attachment of *S. aureus* to each glove surface using the same

inoculation conditions. Fig. 6 shows the SEM micrographs of latex, nitrile, and polyethylene glove surfaces after 1 h and 24 h inoculation with *S. aureus*. After 1 h exposure to bacteria, a mean density of bacteria present on bare latex, nitrile, and polyethylene gloves was 4.3 ± 0.3 log cells/mm², 4.2 ± 0.2 log cells/mm², and 4.3 ± 0.1 log cells/mm², respectively (Figs. 6a-c). Inoculation of FSN-coated gloves resulted in mean densities of 2.4 ± 0.0 log cells/mm², 2.5 ± 0.2 log cells/mm², and 2.5 ± 0.2 log cells/mm², respectively (Figs. 6d-f), which corresponds to reduction in bacterial attachment by >98.1% upon 1 h inoculation. After 24 h exposure to bacteria, a mean density of bacteria present on bare latex, nitrile, and polyethylene gloves was 4.9 ± 0.2 log cells/mm², 4.9 ± 0.3 log cells/mm², and 5.1 ± 0.1 log cells/mm², respectively (Figs. 6g-i). Inoculation of FSN-coated latex, nitrile, and polyethylene gloves resulted in mean densities of 2.7 ± 0.3 log cells/mm², 2.9 ± 0.2 log cells/mm², and 2.9 ± 0.2 log cells/mm², respectively (Figs. 6j-l). These data indicate that bacterial attachment was reduced by >99.1% on FSN-coated gloves compared to bare gloves upon 24 h inoculation.

Both plate count and SEM results demonstrated that superhydrophobic FSN-coated gloves effectively inhibit bacterial attachment in comparison to bare gloves. Even with 24 h exposure to bacterial suspensions, *S. Typhimurium* LT2 and *S. aureus* were less likely to reside on FSN-coated glove surfaces. This phenomenon can be explained in terms of the wetting transition from the Wenzel state to the Cassie-Baxter state due to FSN coating on the surfaces (Chen et al., 2012). The transition into the Cassie-Baxter state implies that air-pockets form when water comes into contact with glove surfaces, thereby decreasing effective (real) contact area between glove surfaces and water containing bacterial pathogens (Crick et al., 2011). Our results can also be explained in terms of hydrophobic effect (Chandler, 2005; Neu, 1996). Prior studies showed that the water contact angle of *S. Typhimurium* LT2 and *S. aureus* layer collected on a filter ranged from 15° to 27° (Dickson and Koohmaraie, 1989; van Loosdrecht et al., 1987). When these bacteria with highly hydrophilic cell surfaces come into contact with nonpolar surfaces, unfavorable intermolecular interactions arise, inhibiting bacterial attachment.

3.4. Mechanical robustness and chemical stability of FSN-coated gloves

Maintaining superhydrophobic properties of FSN-coated gloves are important to ensure bacterial antiadhesion performance of the coating during usage. In this context, we evaluated shear strength of FSN coating on gloves to determine mechanical durability of FSN-coated

gloves (Fig. 7a). All shearing experiments were carried out under the normal load of 10 mN for 10 cycles using a produce-attached tip. As shown in Figs. 7b-g, FSN-coated glove surfaces showed similar surface morphology before and after shearing with a produce-attached tip, indicating practical mechanical durability. Furthermore, difference in surface roughness values before and after shearing were measured using a profilometer. Before shearing, RMS roughness of FSN-coated latex, nitrile, and polyethylene glove surfaces were 419 ± 34 nm, 406 ± 28 nm, and 395 ± 40 nm, respectively. Similar results were obtained after shearing as well: 426 ± 42 nm, 405 ± 47 nm, and 403 ± 43 nm, respectively, which indicates mechanical durability of FSN-coated gloves.

The potential toxicity, if any, of the developed gloves are directly related to the ability to leach chemicals from their FDTS-functionalized silica nanoparticle surfaces through detachment, degradation, or decomposition of fluoro groups. Hence, we investigated chemical stability of FSN-coated gloves in DI water as a function of time using ATR-FTIR spectroscopy. Unbound FDTS molecules had symmetric and asymmetric C-F stretching peak near 1050 cm^{-1} . The spectroscopic analysis revealed that FSN-coated gloves submerged in DI water had no chemical leaching and present the absences of free chemicals within the detection limit of 1 ppm at least in a 24-hour period (Fig. 8).

4. Conclusions

Cross-contamination and transmission of pathogenic bacteria during food processing and handling has become an issue throughout the world. Gloves are the most commonly used protective equipment or barriers against bacterial contamination. However, recent studies have pointed out that the use of gloves, while improving food safety to some extent, may be insufficient to completely prevent the spread of pathogenic bacteria. Herein, we report surface modification of latex, nitrile, and polyethylene gloves with “fluorinated silica nanoparticles” (FSNs) to limit bacterial adhesion. This in turn should reduce the risk of potential cross-contamination and transmission of pathogenic bacteria associated with glove surfaces. The bacterial antiadhesive (antifouling) properties of FSN-coated gloves was confirmed against Gram-negative *S. Typhimurium* LT2 and Gram-positive *S. aureus*, with significantly greater (1–2 log units) bacterial populations on bare gloves than on modified gloves, via plate counting and direct SEM visualization after dip-inoculation. The ability of FSN-coated gloves to inhibit

bacterial attachment is attributed to their nanotextured morphology and low surface energy, the synergistic combination of which leads to superhydrophobic surfaces. Superhydrophobicity translates into a reduced effective (real) contact between glove surfaces and water containing bacterial pathogens, decreasing the probability of bacteria to reach glove surfaces. Overall, the promising bacterial antiadhesive properties of FSN-coated gloves as well as a scalable and facile nature of the application method (i.e., dip-coating) can offer a simple solution for enhancing microbiological food safety and hygiene of disposable gloves used in the food industry.

Acknowledgements

This project was supported by the Agriculture and Food Research Initiative (AFRI) Competitive Grant No. 2011-67017-30028 from the National Institute of Food and Agriculture (NIFA), U.S. Department of Agriculture (USDA) to M. A., J. K. O., and L. C.-Z., and by the NSF Grant No. 1511626 to M. Z. and Y. M.

References

- Akhtar, S., Sarker, M.R., & Hossain, A. (2014). Microbiological food safety: A dilemma of developing societies. *Critical Reviews in Microbiology*, 40(4), 348–359. doi:10.3109/1040841X.2012.742036
- Azlin-Hasim, S., Cruz-Romero, M.C., Ghoshal, T., Morris, M.A., Cummins, E., & Kerry, J.P. (2015). Application of silver nanodots for potential use in antimicrobial packaging applications. *Innovative Food Science & Emerging Technologies*, 27, 136–143. doi:10.1016/j.ifset.2014.10.012
- Barza, M. (2004). Efficacy and tolerability of ClO₂-generating gloves. *Clinical Infectious Diseases*, 38(6), 857–863. doi:10.1086/382535
- Bastarrachea, L.J., Denis-Rohr, A., & Goddard, J.M. (2015). Antimicrobial food equipment coatings: Applications and challenges. *Annual Review of Food Science and Technology*, 6(1), 97–118. doi:10.1146/annurev-food-022814-015453
- Bixler, G.D., & Bhushan, B. (2014). Rice- and butterfly-wing effect inspired self-cleaning and low drag micro/nanopatterned surfaces in water, oil, and air flow. *Nanoscale*, 6(1), 76–96. doi:10.1039/C3NR04755E
- Boks, N.P., Norde, W., van der Mei, H.C., & Busscher, H.J. (2008). Forces involved in bacterial adhesion to hydrophilic and hydrophobic surfaces. *Microbiology*, 154(10), 3122–3133. doi:10.1099/mic.0.2008/018622-0
- Brar, P.K., & Danyluk, M.D. (2013). *Salmonella* transfer potential during hand harvesting of tomatoes under laboratory conditions. *Journal of Food Protection*, 76(8), 1342–1349. doi:10.4315/0362-028X.JFP-13-048
- Cañas, N., Kamperman, M., Völker, B., Kroner, E., McMeeking, R.M., & Arzt, E. (2012). Effect of nano- and micro-roughness on adhesion of bioinspired micropatterned surfaces. *Acta Biomaterialia*, 8(1), 282–288. doi:10.1016/j.actbio.2011.08.028
- Chandler, D. (2005). Interfaces and the driving force of hydrophobic assembly. *Nature*, 437(7059), 640–7. doi:10.1038/nature04162
- Chang, A.S., & Schneider, K.R. (2012). Evaluation of overhead spray-applied sanitizers for the reduction of *Salmonella* on tomato surfaces. *Journal of Food Science*, 77(1), M65–M69. doi:10.1111/j.1750-3841.2011.02486.x

389 Chen, L., Yang, G., & Wang, S. (2012). Air-grid surface patterning provided by superhydrophobic surfaces. *Small*,
390 8(7), 962–965. doi:10.1002/sml.201102345

391 Cheng, G., Zhang, Z., Chen, S., Bryers, J.D., & Jiang, S. (2007). Inhibition of bacterial adhesion and biofilm
392 formation on zwitterionic surfaces. *Biomaterials*, 28(29), 4192–4199. doi:10.1016/j.biomaterials.2007.05.041

393 Chmielewski, R.A.N., & Frank, J.F. (2003). Biofilm formation and control in food processing facilities.
394 *Comprehensive Reviews in Food Science and Food Safety*, 2(1), 22–32. doi:10.1111/j.1541-
395 4337.2003.tb00012.x

396 Corcoran, M., Morris, D., De Lappe, N., O'Connor, J., Lalor, P., Dockery, P., & Cormican, M. (2014). Commonly
397 used disinfectants fail to eradicate *Salmonella enterica* biofilms from food contact surface materials. *Applied*
398 *and Environmental Microbiology*, 80(4), 1507–14. doi:10.1128/AEM.03109-13

399 Crick, C.R., Ismail, S., Pratten, J., & Parkin, I.P. (2011). An investigation into bacterial attachment to an elastomeric
400 superhydrophobic surface prepared via aerosol assisted deposition. *Thin Solid Films*, 519(11), 3722–3727.
401 doi:10.1016/j.tsf.2011.01.282

402 DeVita, M.D., Wadhera, R.K., Theis, M.L., & Ingham, S.C. (2007). Assessing the potential of *Streptococcus*
403 *pyogenes* and *Staphylococcus aureus* transfer to foods and customers via a survey of hands, hand-contact
404 surfaces and food-contact surfaces at foodservice facilities. *Journal of Foodservice*, 18(2), 76–79.
405 doi:10.1111/j.1745-4506.2007.00049.x

406 Dickson, J.S., & Koohmaraie, M. (1989). Cell surface charge characteristics and their relationship to bacterial
407 attachment to meat surfaces. *Applied and Environmental Microbiology*, 55(4), 832–6. Retrieved from
408 <http://www.ncbi.nlm.nih.gov/pubmed/2499255>

409 Ding, X., Yang, C., Lim, T. P., Hsu, L.Y., Engler, A.C., Hedrick, J.L., & Yang, Y.-Y. (2012). Antibacterial and
410 antifouling catheter coatings using surface grafted PEG-b-cationic polycarbonate diblock copolymers.
411 *Biomaterials*, 33(28), 6593–6603. doi:10.1016/j.biomaterials.2012.06.001

412 Epstein, A.K., Wong, T.-S., Belisle, R.A., Boggs, E.M., & Aizenberg, J. (2012). Liquid-infused structured surfaces
413 with exceptional anti-biofouling performance. *Proceedings of the National Academy of Sciences*, 109(33),
414 13182–13187. doi:10.1073/pnas.1201973109

415 Fadeeva, E., Truong, V.K., Stiesch, M., Chichkov, B.N., Crawford, R.J., Wang, J., & Ivanova, E.P. (2011). Bacterial
416 retention on superhydrophobic titanium surfaces fabricated by femtosecond laser ablation. *Langmuir*, 27(6),
417 3012–3019. doi:10.1021/la104607g

418 Flint, S.H., Brooks, J.D., & Bremer, P.J. (2000). Properties of the stainless steel substrate, influencing the adhesion
419 of thermo-resistant streptococci. *Journal of Food Engineering*, 43(4), 235–242. doi:10.1016/S0260-
420 8774(99)00157-0

421 Fu, J., Ji, J., Yuan, W., & Shen, J. (2005). Construction of anti-adhesive and antibacterial multilayer films via layer-
422 by-layer assembly of heparin and chitosan. *Biomaterials*, 26(33), 6684–6692.
423 doi:10.1016/j.biomaterials.2005.04.034

424 Fürstner, R., Barthlott, W., Neinhuis, C., & Walzel, P. (2005). Wetting and self-cleaning properties of artificial
425 superhydrophobic surfaces. *Langmuir*, 21(3), 956–961. doi:10.1021/la0401011

426 Green, L.R., Radke, V., Mason, R., Bushnell, L., Reimann, D.W., Mack, J.C., Motsinger, M.D., Stigger, T., &
427 Selman, C.A. (2007). Factors related to food worker hand hygiene practices. *Journal of Food Protection*,
428 70(3), 661–6. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/17388056>

429 Hare, E.F., Shafrin, E.G., & Zisman, W.A. (1954). Properties of films of adsorbed fluorinated acids. *The Journal of*
430 *Physical Chemistry*, 58(3), 236–239. doi:10.1021/j150513a011

431 Jin, C., Jiang, Y., Niu, T., & Huang, J. (2012). Cellulose-based material with amphiphobicity to inhibit bacterial
432 adhesion by surface modification. *Journal of Materials Chemistry*, 22(25), 12562. doi:10.1039/c2jm31750h

433 Kaneko, K., Hayashidani, H., Takahashi, K., Shiraki, Y., Limawongpranee, S., & Ogawa, M. (1999). Bacterial
434 contamination in the environment of food factories processing ready-to-eat fresh vegetables. *Journal of Food*

Protection, 62(7), 800–4. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/10419276>

- Kirk, M.D., Pires, S.M., Black, R.E., Caipo, M., Crump, J.A., Devleesschauwer, B., Döpfer, D., Fazil, A., Fischer-Walker, C.L., Hald, T., Hall, A.J., Keddy, K.H., Lake, R.J., Lanata, C.F., Torgerson, P.R., Havelaar, A.H., & Angulo, F.J. (2015). World Health Organization estimates of the global and regional disease burden of 22 foodborne bacterial, protozoal, and viral diseases, 2010: A data synthesis. *PLOS Medicine*, 12(12), e1001921. doi:10.1371/journal.pmed.1001921
- Kotwal, G., Lee, C.-C., Kang, W., & Cannon, J. (2014). Comparative study of human finger pads and porcine skins used to quantify cross-contamination by norovirus and *Salmonella* during glove application and food handling. In *2014 IAFP Annual Meeting*. Retrieved from <https://iafp.confex.com/iafp/2014/webprogram/Paper6835.html>
- Lavoine, N., Givord, C., Tabary, N., Desloges, I., Martel, B., & Bras, J. (2014). Elaboration of a new antibacterial bio-nano-material for food-packaging by synergistic action of cyclodextrin and microfibrillated cellulose. *Innovative Food Science & Emerging Technologies*, 26, 330–340. doi:10.1016/j.ifset.2014.06.006
- Leitgeb, J., Schuster, R., Eng, A.-H., Yee, B.-N., Teh, Y.-P., Dosch, V., & Assadian, O. (2013). In-vitro experimental evaluation of skin-to-surface recovery of four bacterial species by antibacterial and non-antibacterial medical examination gloves. *Antimicrobial Resistance and Infection Control*, 2(1), 27. doi:10.1186/2047-2994-2-27
- Levy, S.B., & Marshall, B. (2004). Antibacterial resistance worldwide: Causes, challenges and responses. *Nature Medicine*, 10(12s), S122–S129. doi:10.1038/nm1145
- Lorenzetti, M., Dogša, I., Stošicki, T., Stopar, D., Kalin, M., Kobe, S., & Novak, S. (2015). The influence of surface modification on bacterial adhesion to titanium-based substrates. *ACS Applied Materials & Interfaces*, 7(3), 1644–1651. doi:10.1021/am507148n
- Neu, T.R. (1996). Significance of bacterial surface-active compounds in interaction of bacteria with interfaces. *Microbiological Reviews*, 60(1), 151–66. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/8852899>
- Nguyen, H.D.N., & Yuk, H.-G. (2013). Changes in resistance of *Salmonella* Typhimurium biofilms formed under various conditions to industrial sanitizers. *Food Control*, 29(1), 236–240. doi:10.1016/j.foodcont.2012.06.006
- Oh, J.K., Kohli, N., Zhang, Y., Min, Y., Jayaraman, A., Cisneros-Zevallos, L., & Akbulut, M. (2016). Nanoporous aerogel as a bacteria repelling hygienic material for healthcare environment. *Nanotechnology*, 27(8), 085705. doi:10.1088/0957-4484/27/8/085705
- Oh, J.K., Lu, X., Min, Y., Cisneros-Zevallos, L., & Akbulut, M. (2015). Bacterially antiadhesive, optically transparent surfaces inspired from rice leaves. *ACS Applied Materials & Interfaces*, 7(34), 19274–19281. doi:10.1021/acsami.5b05198
- Oh, J.K., Perez, K., Kohli, N., Kara, V., Li, J., Min, Y., Castillo, A., Taylor, M., Jayaraman, A., Cisneros-Zevallos, L., & Akbulut, M. (2015). Hydrophobically-modified silica aerogels: Novel food-contact surfaces with bacterial anti-adhesion properties. *Food Control*, 52, 132–141. doi:10.1016/j.foodcont.2014.12.029
- Painter, J.A., Hoekstra, R.M., Ayers, T., Tauxe, R.V., Braden, C.R., Angulo, F.J., & Griffin, P.M. (2013). Attribution of foodborne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998–2008. *Emerging Infectious Diseases*, 19(3), 407–415. doi:10.3201/eid1903.111866
- Park, K.D., Kim, Y.S., Han, D.K., Kim, Y.H., Lee, E.H.B., Suh, H., & Choi, K.S. (1998). Bacterial adhesion on PEG modified polyurethane surfaces. *Biomaterials*, 19(7-9), 851–859. doi:10.1016/S0142-9612(97)00245-7
- Pettersson, A., Ohlsson, T., Davis, S., Gray, J.O., & Dodd, T.J. (2011). A hygienically designed force gripper for flexible handling of variable and easily damaged natural food products. *Innovative Food Science & Emerging Technologies*, 12(3), 344–351. doi:10.1016/j.ifset.2011.03.002
- Puckett, S.D., Taylor, E., Raimondo, T., & Webster, T.J. (2010). The relationship between the nanostructure of titanium surfaces and bacterial attachment. *Biomaterials*, 31(4), 706–713. doi:10.1016/j.biomaterials.2009.09.081
- Rasko, D.A., & Sperandio, V. (2010). Anti-virulence strategies to combat bacteria-mediated disease. *Nature*

481 *Reviews Drug Discovery*, 9(2), 117–128. doi:10.1038/nrd3013

482 Reitzel, R.A., Dvorak, T.L., Hachem, R.Y., Fang, X., Jiang, Y., & Raad, I. (2009). Efficacy of novel antimicrobial
 483 gloves impregnated with antiseptic dyes in preventing the adherence of multidrug-resistant nosocomial
 484 pathogens. *American Journal of Infection Control*, 37(4), 294–300. doi:10.1016/j.ajic.2008.07.003

485 Shi, X., & Zhu, X. (2009). Biofilm formation and food safety in food industries. *Trends in Food Science &*
 486 *Technology*, 20(9), 407–413. doi:10.1016/j.tifs.2009.01.054

487 Shivapooja, P., Wang, Q., Orihuela, B., Rittschof, D., López, G.P., & Zhao, X. (2013). Bioinspired surfaces with
 488 dynamic topography for active control of biofouling. *Advanced Materials*, 25(10), 1430–1434.
 489 doi:10.1002/adma.201203374

490 Stalder, A.F., Melchior, T., Müller, M., Sage, D., Blu, T., & Unser, M. (2010). Low-bond axisymmetric drop shape
 491 analysis for surface tension and contact angle measurements of sessile drops. *Colloids and Surfaces A:*
 492 *Physicochemical and Engineering Aspects*, 364(1–3), 72–81. doi:10.1016/j.colsurfa.2010.04.040

493 Sung, S.-Y., Sin, L.T., Tee, T.-T., Bee, S.-T., & Rahmat, A.R. (2014). Effects of *Allium sativum* essence oil as
 494 antimicrobial agent for food packaging plastic film. *Innovative Food Science & Emerging Technologies*, 26,
 495 406–414. doi:10.1016/j.ifset.2014.05.009

496 Surowsky, B., Schlüter, O., & Knorr, D. (2015). Interactions of non-thermal atmospheric pressure plasma with solid
 497 and liquid food systems: A review. *Food Engineering Reviews*, 7(2), 82–108. doi:10.1007/s12393-014-9088-5

498 Tauxe, R.V., Doyle, M.P., Kuchenmüller, T., Schlundt, J., & Stein, C.E. (2010). Evolving public health approaches
 499 to the global challenge of foodborne infections. *International Journal of Food Microbiology*, 139, S16–S28.
 500 doi:10.1016/j.ijfoodmicro.2009.10.014

501 Todd, E.C.D., Greig, J.D., Bartleson, C.A., & Michaels, B.S. (2007). Outbreaks where food workers have been
 502 implicated in the spread of foodborne disease. Part 3. Factors contributing to outbreaks and description of
 503 outbreak categories. *Journal of Food Protection*, 70(9), 2199–217. Retrieved from
 504 <http://www.ncbi.nlm.nih.gov/pubmed/17900100>

505 Todd, E.C.D., Michaels, B.S., Greig, J.D., Smith, D., & Bartleson, C.A. (2010). Outbreaks where food workers have
 506 been implicated in the spread of foodborne disease. Part 8. Gloves as barriers to prevent contamination of food
 507 by workers. *Journal of Food Protection*, 73(9), 1762–73. Retrieved from
 508 <http://www.ncbi.nlm.nih.gov/pubmed/20828485>

509 Truong, V.K., Lapovok, R., Estrin, Y.S., Rundell, S., Wang, J. Y., Fluke, C.J., Crawford, R.J., & Ivanova, E.P.
 510 (2010). The influence of nano-scale surface roughness on bacterial adhesion to ultrafine-grained titanium.
 511 *Biomaterials*, 31(13), 3674–3683. doi:10.1016/j.biomaterials.2010.01.071

512 van Loosdrecht, M.C., Lyklema, J., Norde, W., Schraa, G., & Zehnder, A.J. (1987). The role of bacterial cell wall
 513 hydrophobicity in adhesion. *Applied and Environmental Microbiology*, 53(8), 1893–7. Retrieved from
 514 <http://www.ncbi.nlm.nih.gov/pubmed/2444158>

515 Vansant, E.F., Voort, P. Van Der, & Vrancken, K.C. (1995). Chapter 1 Silica: Preparation and properties. In *Studies*
 516 *in Surface Science and Catalysis* (Vol. 93, pp. 3–30). doi:10.1016/S0167-2991(06)81509-0

517 Wu, Y., Zitelli, J.P., TenHuisen, K.S., Yu, X., & Libera, M.R. (2011). Differential response of *Staphylococci* and
 518 osteoblasts to varying titanium surface roughness. *Biomaterials*, 32(4), 951–960.
 519 doi:10.1016/j.biomaterials.2010.10.001

520 Yang, W. J., Cai, T., Neoh, K.-G., Kang, E.-T., Dickinson, G.H., Teo, S. L.-M., & Rittschof, D. (2011). Biomimetic
 521 anchors for antifouling and antibacterial polymer brushes on stainless steel. *Langmuir*, 27(11), 7065–7076.
 522 doi:10.1021/la200620s

523 Zeitler, V.A., & Brown, C. A. (1957). The infrared spectra of some Ti-O-Si, Ti-O-Ti and Si-O-Si compounds. *The*
 524 *Journal of Physical Chemistry*, 61(9), 1174–1177. doi:10.1021/j150555a010

525 Zhang, M., Oh, J.K., Huang, S.-Y., Lin, Y.-R., Liu, Y., Mannan, M.S., Cisneros-Zevallos, L., & Akbulut, M. (2015).
 526 Priming with nano-aerosolized water and sequential dip-washing with hydrogen peroxide: An efficient

527 sanitization method to inactivate *Salmonella* Typhimurium LT2 on spinach. *Journal of Food Engineering*,
528 161(0), 8–15. doi:http://dx.doi.org/10.1016/j.jfoodeng.2015.03.026

529 Zhang, M., Yang, F., Pasupuleti, S., Oh, J.K., Kohli, N., Lee, I.-S., Perez, K., Verkhouturov, S. V., Schweikert, E.A.,
530 Jayaraman, A., Cisneros-Zevallos, L., & Akbulut, M. (2014). Preventing adhesion of *Escherichia coli*
531 O157:H7 and *Salmonella* Typhimurium LT2 on tomato surfaces via ultrathin polyethylene glycol film.
532 *International Journal of Food Microbiology*, 185(0), 73–81. doi:10.1016/j.ijfoodmicro.2014.05.019

533 Zhang, X., Wang, L., & Levänen, E. (2013). Superhydrophobic surfaces for the reduction of bacterial adhesion. *RSC*
534 *Advances*, 3(30), 12003. doi:10.1039/c3ra40497h

Fig. 1. Schematic illustration of surface modification of disposable gloves with “fluorinated silica nanoparticles” (FSNs) to achieve bacteria-repellent and antiadhesive (antifouling) properties.

Fig. 2. SEM micrographs of FSN-coated (a) latex, (b) nitrile, and (c) polyethylene glove surfaces. Insets: SEM micrographs of bare latex, nitrile, and polyethylene glove surfaces, respectively.

Fig. 3. (a) C-F stretching region from ATR-FTIR spectra of bare and FSN-coated gloves. (b)-(g) The static water contact angle measurements of bare and FSN-coated gloves.

Fig. 4. The comparison of bacterial attachment to bare and FSN-coated gloves for (a) *S. Typhimurium* LT2 and (b) *S. aureus* upon 1 h exposure to bacteria. The data were obtained by the pour plating method. The number of stars (i.e., * and **) indicate a statistically significant difference ($p < 0.05$) between bare and FSN-coated gloves.

Fig. 5. SEM micrographs of attached *S. Typhimurium* LT2 to bare and FSN-coated gloves after (a)-(f) 1 h and (g)-(l) 24 h exposure to bacteria. Bacteria on glove surfaces were highlighted with green.

Fig. 6. SEM micrographs of attached *S. aureus* to bare and FSN-coated gloves after (a)-(f) 1 h and (g)-(l) 24 h exposure to bacteria. Bacteria on glove surfaces were highlighted with green.

Fig. 7. (a) Schematic drawing of shear test setup to evaluate mechanical durability between produce-attached tip and FSN-coated glove surfaces. SEM micrographs of before (b)-(d) and after (e)-(f) shear test, showing shear resistance of FSN-coated gloves.

Fig. 8. ATR-FTIR spectra of aliquots collected from the samples (i.e., FSN-coated glove pieces submerged in DI water). The absence of C-F stretching region suggest chemical stability of functional groups on glove surfaces.