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Assessment of a handheld fluorescence imaging device as an aid for detection of food residues on processing surfaces

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ABSTRACT

Contamination of food with pathogenic bacteria can lead to foodborne illnesses. Food processing surfaces can serve as a medium for cross-contamination if sanitization procedures are inadequate. Ensuring that food processing surfaces are correctly cleaned and sanitized is important in the food industry to reduce risks of foodborne illnesses and their related costs. A handheld fluorescence imaging device was assessed for detection of three types of food residues that have been associated with foodborne illness outbreaks, i.e. spinach leaf, milk, and bovine red meat, on two commonly used processing surfaces, i.e. high-density polyethylene and food grade stainless steel. Fluorescence excitation at 405 nm was supplied by 4 × 10 W light emitting diodes. Interchangeable optical filters were selected to optimise the contrast between the food residues and processing surfaces, using hyperspectral fluorescence imaging. The fluorescence imaging plus image analysis differentiated food residues from the processing surfaces more clearly than visual inspection in ambient lighting. This optical sensing device can be used to detect food fouling on food processing surfaces over relatively large areas, and has potential for use in the food industry as an aid for detection of specific food residues.

1. Introduction

Food fouling of processing surfaces is a major concern for the food industry, as it can lead to food safety issues (Barish & Goddard, 2014; De Jong, 1997). Accumulation of food residue can provide an environment for microbial growth and biofilm formation (Agle, 2007; Barish & Goddard, 2014; Parkar, Flint, & Brooks, 2004). Microorganisms can grow rapidly in food residues remaining on food processing or handling equipment after use (Jun et al., 2010). Controlling microorganisms is essential in food processing, in order to provide safe, wholesome, and palatable food to consumers (Hood & Zottola, 1995). Painter et al. (2013) estimated that more than 9 million foodborne illnesses are caused by pathogens each year. Cross-contamination with pathogenic bacteria such as *Escherichia coli* O157:H7, *Salmonella enterica*, and *Listeria monocytogenes* from food processing surfaces to food products can occur due to inadequate cleaning or sanitizing (Jun et al., 2010; Reij & Den Aantrekker, 2004). Processing such as trimming, cutting, washing, rinsing, dewatering, and packaging are points of potential cross-contamination during fresh produce production (Srey, Jahid, & Ha, 2013). For example, Haeghebaert, Le Querrec, Vaillant, Delarocque Astagneau, and Bouvet (2001) suggested that 40% of the foodborne diseases caused by bacteria between 1996 and 1998 in France were related to contaminated equipment. Prolonging the shelf-life of fresh-cut produce can be achieved by washing, and inclusion of sanitizers in the wash solutions can reduce bacterial counts by as much as 2 log (Srey et al., 2013; Whipps, Hand, Pink, & Bending, 2008). However, foodborne pathogens such as *L. monocytogenes* can be difficult to eliminate, as they can survive extreme conditions of temperature, pH, and salts (Cole, Jones, & Holyoak, 1990; Koo, Ndahetuye, O'Bryan, Ricke, & Crandall, 2014). Diligent cleaning and sanitation inspection by restaurant owners, food suppliers, caterers, and others who handle and serve large volumes of food are necessary to reduce foodborne illnesses.

Fresh produce has a high risk of association with foodborne illness because there is no lethal phase (e.g. heating to kill pathogens) before it is consumed (Wiederoder, Liu, Lefcourt, Kim, & Lo, 2013). Leafy greens have an enhanced risk of contamination in the field with pathogenic bacteria from fecal matter from livestock or wild animals that may enter the field (Everard, Kim, & Lee, 2014).

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Milk is vulnerable to contamination by microorganisms from ineffectively cleaned and sanitized equipment (Jessen & Lammert, 2003; Koutzayiotis, 1992; Srey et al., 2013). For example, the recall of approximately 20 pounds of raw milk in 2011 in Washington State, USA, due to *L. monocytogenes* contamination was thought to be associated with biofilm formation (Srey et al., 2013). Bacteria of the genera *Enterobacter, Listeria, Lactobacillus, Micrococcus, Streptococcus, Bacillus*, and *Pseudomonas* are frequently encountered in the dairy environment (Salo, Ehavald, Raaska, Vokk, & Wirtanen, 2006; Sharma & Anand, 2002; Waak, Tham, & Danielsson-Tham, 2002).

Cross-contamination of meat products is a concern, because some cooking practices do not kill all pathogenic bacteria. Contamination can occur during the slaughtering, dressing, chilling, or cutting stages of processing (Dourou et al., 2011; Koutsoumanis & Sofos, 2004). Many reports demonstrate the potential for cross contamination with *E. coli* O157:H7 via surfaces of equipment used for beef processing (Aslam, Greer, Nattress, Gill, & McMullen, 2004; Gill & McGinnis, 2000; Gun, Yilmaz, Turker, Tanlasi, & Yilmaz, 2003).

Biofilm formation is recognized as a frequent source of cross-contamination in the food industry, because it allows bacteria to resist cleaning and disinfection. The biofilm serves as a barrier to prevent or lessen contact with the disinfectant (O'Toole & Kaplan, 2000; Srey et al., 2013). Biofilms are usually composed of water, proteins, lipids, and polysaccharides, as well as the bacteria (Donlan & Costerton, 2002; Jun et al., 2010). Srey et al. (2013) described five steps of biofilm formation, i.e. (1) initial attachment, (2) irreversible attachment, (3) early development of biofilm architecture, (4) maturation, and (5) dispersion. The final step enables cross-contamination by releasing pathogens back into the surrounding environment (Silagyi, Kim, Lo, & Wei, 2009). The attachment and formation of biofilms containing pathogenic microorganisms in food residues on processing surfaces or equipment is of major concern to food processors, because it can lead to cross-contamination and has the potential for major heath and economic consequences (Dourou et al., 2011).

The role of food processing surface material, plant design, cleaning procedures, and sanitizers in ensuring safe food production are widely reported (Hadjiev, Dimitrov, Martinov, & Sire, 2007; Le Gentil, Sylla, & Faille, 2010; Palmer, Flint, & Brooks, 2007). Many products are available for cleaning of food processing surfaces, including surfactants and alkali products (Srey et al., 2013). Popular types of disinfectants include chlorine, hydrogen peroxide, iodine, ozone, and peracetic acid (Chmielewski & Frank, 2007; Srey et al., 2013). The effectiveness of antimicrobial agents in killing microorganisms is reduced by the presence of organic food residues (Srey et al., 2013). Cleaning can be targeted to dissolve the extracellular polymeric substance (EPS) matrix of biofilms, which allows the disinfectants to kill the bacterial cells that were protected by the matrix (Simões, Simões, Machado, Pereira, & Vieira, 2006; Srey et al., 2013). Clean in place (CIP) is a commonly-used process in the food industry, whereby the processing system is cleaned without dismantling and without an operator (Srey et al., 2013). CIP procedures and their effectiveness have been reported (Boulange-Petermann, Jullien, Dubois, Benezech, & Faille, 2004; Lelièvre, Antonini, Faille, & Bénézech, 2002).

An important step in food safety is to ensure that the cleaning and sanitizing procedures have been effective. Cleaning and sanitation inspections usually involve visual inspection, adenosine triphosphate (ATP) bioluminescence assays, and culturing techniques such as rapid PCR, to assess sanitation effectiveness and reduce cross-contamination (Moore & Griffith, 2002; Wiederoder et al., 2013).

The ATP bioluminescence assay is a widely used method to monitor food processing surfaces in the food industry (Davidson, Griffith, Peters, & Fielding, 1999; Koo et al., 2013). The results are available within a few minutes but the assay detects both microorganisms and food residues, which can lead to inconsistent correlation with the level of bacterial contamination (Aycicek, Oguz, & Karci, 2006; Koo et al., 2013). In contrast, rapid PCR cultures take 24–48 h to obtain results (Pérez-Rodríguez, Valero, Carrasco, García, & Zurera, 2008). However, since DNA can remain intact for up to 3 weeks after cell death, this can lead to overestimation or false positives in the detection of living microorganisms (Martinon, Cronin, Quealy, Stapleton, & Wilkinson, 2012; Nocker, Cheung, & Camper, 2006). Another method which can provide accurate, real-time results over large areas is needed (Wiederoder et al., 2013).

Non-destructive and non-contact optical techniques that can monitor large areas and rapidly detect anomalies have gained considerable interest in the food industry (Everard et al., 2014; Jun et al., 2010). Many organic compounds fluoresce in the visual and near infrared wavebands when exposed to ultraviolet or violet excitation. This property could be utilized to detect contamination on food processing surfaces.

Chlorophyll a has a distinctive fluorescence emission profile, with peaks near 685 and 730 nm (Everard et al., 2014). Fluorescence emissions peaks for other plant constituents have been reported near 340, 450 and 530 nm (Corp, McMurtrey, Chappelle, Daughtry, & Kim, 1997; Kim, McMurtrey, Mulchi, Daughtry, Chappelle, & Chen, 2001). Milk components that fluoresce include aromatic amino acids, vitamin A, and riboflavin (Christensen, Becker, & Frederiksen, 2005). Processing of milk also forms fluorescent compounds, e.g. Maillard reaction products (Birlouez-Aragon et al., 1998; Birlouez-Aragon, Sabat, & Gouti, 2002). Meat products have high florescence emissions in the ultraviolet (UV) and blue-green regions of the spectrum; the UV emissions are related to protein, and the blue–green emissions are associated with aromatic compounds (Wold & Kvaal, 2000; Wold, Lundby, & Egelandsdal, 1999).

A handheld fluorescence imaging device could be a useful aid for detection of food residues which are not easily discernible by the human eye (Cho, Chen, & Kim, 2007). Additional anticipated benefits of fluorescence imaging would be that larger areas than possible by swab sampling techniques could be assessed, and in real-time. The objectives of this study were to assess the usefulness of a recently developed handheld fluorescence imaging device (HFID), engineered in-house, to detect food residues on typical types of food processing surfaces. Fluorescence emission profiles, captured using hyperspectral fluorescence imaging, were used to identify the fluorescence emissions from tested materials, and to select appropriate optical filters for differentiating the food residues from the processing surfaces.

2. Material and methods

2.1. Fouling of food processing surfaces with food residues

Two widely used food processing surface materials were used in this study, i.e. 45 cm × 45 cm × 6 mm white high-density polyethylene (HDPE) sheets (The Cutting Board Factory, Carbondale, PA, USA) and 45 cm × 45 cm food grade 304 stainless steel (SS) sheets (2B finish; Stainless Supply, Monroe, NC, USA). Plastic polymers such as HDPE are often used in the food industry, in the manufacture of conveyor belts (Pompermayer & Gaylarde, 2000) and as a cutting board material (Jun et al., 2010). HDPE fluoresces under violet light, whereas the SS is non-fluorescent (Jun et al., 2010). Stainless steel is the most frequently used material for food