Assessment of interplay between UV wavelengths, material surfaces and food residues in open surface hygiene validation

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Abstract The use of UV-visible radiation for detecting invisible residue on different surfaces as a means of validating cleanliness was investigated. Wavelengths at 365, 395, 435, 445, 470 and 490 nm from a monochromator were used to detect residues of beef, chicken, apple, mango and skim milk. These were on three surfaces: aluminium, fibre re-enforced plastic (FRP; Q-Liner®) and stainless steel, pre- and post a cleaning step using commercial detergent. The area covered by residues as detected by specific wavelengths was compared statistically. The sensitivity of the wavelengths for detection differed significantly ($p < 0.05$) for various residues depending on the material surfaces. Generally, wavelengths 365–445 nm were consistently able to illuminate all residue before cleaning, though sensitivity varied, while 490 nm showed more of the surface structural features instead of residue. The 365–395 nm wavelengths were significantly more sensitive ($p < 0.05$) for detecting beef and chicken residues on aluminium and stainless steel both before and after cleaning. The 435–445 nm wavelengths were significantly more sensitive for detecting apple and mango residues on the FRP both before

and after cleaning. It is important when UV-systems are used as real-time tools for assessing cleanliness of surfaces that the surface materials being illuminated are taken into account in the choice of lamp wavelength, in addition to expected residue. This will ensure higher confidence in results during the use of UV-light for real-time hygiene validation of surfaces.

Keywords UV-light · Cleaning validation · Food contact surfaces

Introduction

The presence of food and other organic soils on food contact surfaces provide a good environment for bacteria survival and growth. They are a source of nutrients and afford the bacteria protection from disinfection, in addition to being indicative of poor hygiene processes (Holah 1995; Verran et al. 2001). Their presence also makes adhered bacteria difficult to detach from the surfaces (Abban et al. 2012). Cleaning and disinfection aims to eliminate food residues along with spoilage and pathogenic microbes from surfaces; thus the desired result of hygiene testing is to ensure that this has been properly achieved (Salo et al. 2008; Sherlock et al. 2009).

Various studies have found that traditional swab and contact agar test are at best only 20 % efficient at elucidating the extent of fouling on a surface (Maukonen et al. 2000; Salo et al. 2000; Verran et al. 2010), while the ATP bioluminescence system produce results that are not always consistent with traditional tests aimed at detecting viable/culturable micro-organisms on surfaces (Odebrecht et al. 2000; Whitehead et al. 2008). The use of ultraviolet (UV) light has been shown to be a reliable, quick and cost effective method of accessing hygiene after cleaning processes in both closed (Salo et al.

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2008) and open surfaces (Verran and Whitehead 2006) in real-time as it visually highlights areas that require further cleaning, ensuring that such surfaces are clean to ‘sight and touch’ (Cunningham et al. 2011; FDA 2009).

Available literature on the use of UV light in food environments for hygiene validation is mostly on stainless steel. However aluminium and various forms of plastic polymers are used in applications that are important in the food chain including transportation (Abban et al. 2012). It has been observed that some plastic materials and imperfections in surface finishing may produce reflections which may be confused with actual fluorescence from soil; hence one possible pitfall of the technique is that experience and previous knowledge is required to correctly apply it in real practice (Förnäs 2006). However to the best of our knowledge, there is no study about the use of UV light for validating cleaning in systems having different materials as part of the design, as is common in the interior of cargo containers used in transporting food. It is not uncommon to find improperly packed and damaged quantities of various foods in cargo containers or other receptacles e.g. originating from dripping residue due to temperature and other abuses. It has been reported in other studies that the UV wavelength band 330–380 nm was appropriate for detection of residual soil from the meat and cheese industry while 510–560 nm (green and yellow regions of visible light) was better for soils from the fish industry, both on stainless steel (Whitehead et al. 2008).

The aim of this work was to evaluate different UV wavelengths used in hygiene validation to detect different food residues on various food contact surface materials (aluminium, stainless steel and fibre re-enforced plastic) before and after a cleaning procedure. Food products such as beef, chicken, apple, mango and skim milk were used as model food residue sources. The AT special detergent (Novadan ApS, Kolding, Denmark) has been used in the work since it is a commercial alkaline detergent used for cleaning such surfaces at the concentration used in the study. The rinsing by vortexing system has also been shown in previous work (Abban et al. 2012) to be of equal efficacy as cleaning with a spray system, and due to its simplicity was chosen for these experiments.

Materials and methods

Food contact surfaces

Plates of three surface materials: aluminium (alloy 5754) and stainless steel (AISI-304) (provided kindly by Flemming Frederiksen, University of Copenhagen), and fibre re-enforce plastic [FRP (Q Liner®), registered product, Maersk Container Industry, Tinglev, Denmark] were cut into 10 mm × 10 mm coupons. These were rinsed in mild soapy water (Softcare, Johnson Diversey, Nivå, Denmark), immersed in

0.01 mol/l nitric acid solution for 30 min, then rinsed with distilled water and allowed to air dry under a laminar fume hood (H.J. Engineering ApS, Galten, Denmark). The surface properties of these materials have been previously described (Abban et al. 2012) with roughness average R_a of 0.41 μm , 0.87 μm and 0.34 μm , and water contact angles of 52.92°, 117.58° and 83.42° for the aluminium, FRP and stainless steel respectively.

Preparation of food residue

Aqueous extracts of lean beef and chicken fillets were obtained by the following method. Fresh produce were obtained from a local supermarket (COOP, Albertslund, Denmark). These were cut into small pieces (approximately 1 cm^3). 200 ml of distilled water was added per 250 g of the pieces and homogenised in a blender (model 34BL99, Waring Inc., Torrington, CT, USA). The suspension was filtered through a nylon cloth. The filtrate was then passed through a standard paper coffee filter and collected in media bottles. Residues of mango and apples were obtained similarly by homogenizing 250 g apple or 100 g mango edible portions respectively with 200 ml distilled water. The mashers were filtered as above. For skim milk residue, a litre of pasteurized carton milk (0.5 % fat, Arla Foods Amba, Viby J, Denmark) was used without any further treatment.

Fouling, cleaning and imaging

Coupons were immersed in 5 ml of residue inside a sterile test tube for 10 min, drained and allowed to dry under a laminar fume hood (H.J. Engineering ApS, Galten, Denmark) for 2 h. The dried residues on the surfaces were mostly visible with the unaided eye under normal white light. Controls consisted of coupons immersed in 5 ml distilled water for 10 min. For imaging, a coupon was placed between two cover slips (cat. No. 631-0145, VWR, Herlev, Denmark) and held in place inside a sample holder. The imaging set-up has been previously described (Guldfeldt and Arneborg 1998; Siegmundfeldt et al. 2000) and consisted of a monochromator providing various excitation wavelengths and an inverted microscope equipped with a ×20 oil immersion objective. Emitted light was recorded with a cooled slow-scan frame transfer charge-coupled device camera (EEV 512 × 512 12-bit frame-transfer CCD; Princeton Instruments Inc., Trenton, N.J.). Images were captured and stored as multiple stacks at the wavelengths 365, 395, 435, 445, 470 and 490 nm for same field view at a time, on the attached personal computer using Metamorph 7.04 (Molecular Devices Inc., Sunnyvale, CA, USA). Representative random field views (15 field view stacks per sample coupon) were taken and analyzed with Image J software (NIH, Bethesda, MA, USA) for percentage area covered by residue per field view. The wavelengths in this work have been chosen between

the bands used by Whitehead et al (2008) and applied as single wavelengths from a monochromator.

Same coupons were each then placed in 3 ml of alkaline detergent solution (2 % AT special, pH10.5, Novadan ApS, Kolding, Denmark) for 5 min after which they were rinsed by placing in a sterile test tube containing 3 ml of sterile distilled water and vortexed at 1800 RPM (IKA, Stufen, Germany) for 10 s (Sharma and Anand 2002). Coupons were drained and air dried under a laminar fume hood and imaged as above. The procedure was done on all substratum coupon types and treatments and repeated in two separate experiments. Coupons were not re-used in this study.

Statistical analysis

Two independent repeat experiments were carried out in this study. For each experiment, several coupons were treated under the various study condition set mentioned above. For each condition set, 15 random repeat images were taken and each one analysed for percentage area covered by the given residue (overall each result presented in Tables 1, 2, 3, 4 and 5 are from analysis of 30 images per condition set investigated). Statistical analysis of percentage area fouled for different wavelengths on the soiled coupon type was carried out using one-way analysis of variance (ANOVA) test; means were separated by Tukey's multiple comparison test (Minitab software ver. 15 for Windows; Minitab Ltd., Coventry UK). The results are reported as mean $\pm$ standard deviation. Probabilities less than 0.05 ($p < 0.05$) were considered significant.

Results and discussion

The use of UV wavelengths in validating level of hygiene after cleaning operations is real-time, cheap, simple and

non-invasive, though it does not give quantitative data in practical use. It is rare to find microorganisms on surfaces in absence of organic materials; however accumulated residue has a major influence on microbial retention afterwards (Verran et al. 2001; Verran et al. 2010).

The differences in detection of beef residue on the various surface types at the studied wavelengths are shown (Table 1). Before cleaning, detection levels at 365–470 nm for aluminium and 365–445 for stainless steel were not significantly different ($p > 0.05$). For both metals, the 490 nm showed more clearly the metal structure rather than adhered residue. The wavelengths used however did not affect significantly the sensitivity in detecting the beef residue on the FRP with values at all wavelengths tested being similar ($p > 0.05$) (Table 1).

Detection sensitivity for chicken residue was significantly lower ($p < 0.05$) at 365 and 395 nm than at wavelengths between 435 and 490 nm on aluminium (Table 2) before cleaning. For the FRP, there was no significant difference in detection sensitivity of chicken residue between all wavelengths tested before cleaning. The detection of chicken residue on stainless steel before cleaning put the wavelengths in 3 groups; 365, 395 and 470 nm in one group, 435 and 445 nm in another and 490 nm in the last, with significant difference between groups ($p < 0.05$) while members of a group had statistically similar detection sensitivities ($p > 0.05$) (Table 2). The findings in this work for beef and chicken are also in agreement with observations by Whitehead et al (2008) who observed that a UV light band of wavelength 330–380 nm was appropriate for detection of residue in the meat and cheese industries.

Generally the cleaning method applied was effective. For instance, the average area covered by beef residue on aluminium detectable at 365 nm for instance was reduced from 29.22 % to 0.175 %, over 100 fold reduction while for chicken residue under similar parameters the reduction was from

Table 1 Average percentage area per field view of material surfaces covered with beef residue before and after cleaning^x

Wavelength (nm)	^y Aluminium		FRP		Stainless steel	
	Before cleaning	After cleaning	Before cleaning	After cleaning	Before cleaning	After cleaning
365	^b 29.2 $\pm$ 25.15 ^a	0.2 $\pm$ 0.28 ^a	1.0 $\pm$ 0.91 ^a	0.3 $\pm$ 0.21 ^a	2.1 $\pm$ 0.67 ^a	0.02 $\pm$ 0.03 ^a
395	28.5 $\pm$ 24.13 ^a	0.2 $\pm$ 0.22 ^a	1.1 $\pm$ 0.82 ^a	0.3 $\pm$ 0.33 ^a	2.0 $\pm$ 0.71 ^a	0.02 $\pm$ 0.03 ^a
435	30.9 $\pm$ 25.46 ^a	0.1 $\pm$ 0.13 ^{abc}	1.2 $\pm$ 0.89 ^a	0.6 $\pm$ 0.63 ^a	2.63 $\pm$ 0.82 ^a	0.02 $\pm$ 0.01 ^a
445	31.1 $\pm$ 25.76 ^a	0.05 $\pm$ 0.08 ^{bc}	1.4 $\pm$ 1.39 ^a	0.4 $\pm$ 0.33 ^a	2.4 $\pm$ 1.00 ^a	0.01 $\pm$ 0.01 ^a
470	28.7 $\pm$ 28.47 ^a	0.004 $\pm$ 0.01 ^b	1.5 $\pm$ 1.67 ^a	0.4 $\pm$ 0.58 ^a	0.4 $\pm$ 0.36 ^b	0.002 $\pm$ 0.003 ^b
490	0.1 $\pm$ 0.08 ^b	0.004 $\pm$ 0.01 ^b	0.8 $\pm$ 1.18 ^a	0.3 $\pm$ 0.61 ^a	0.02 $\pm$ 0.04 ^b	0.001 $\pm$ 0.002 ^b

^x Residue was exposed to surface for 10 min before draining and allowing to dry; cleaning was for 10 s using a commercial detergent. Images ($n = 15$ for each of two independent repeat) were by fluorescent microscopy with a monochromator providing UV illumination

^y Material surfaces used in the study: aluminium (alloy 5754), FRP fibre re-enforced plastic [Q-Liner[®]; Maersk Container Industry (MCI), Tinglev, Denmark], stainless steel (alloy 304)

^{a,b,c} Means with same alphabets in a column do not differ significantly ($p < 0.05$)

Table 2 Average percentage area per field view of material surfaces covered with chicken residue before and after cleaning^x

Wavelength (nm)	^y Aluminium		FRP		Stainless steel	
	Before cleaning	After cleaning	Before cleaning	After cleaning	Before cleaning	After cleaning
365	^c 1.5±0.42 ^a	0.1±0.10 ^a	6.5±3.97 ^a	0.9±0.77 ^a	6.7±2.18 ^a	0.5±0.18 ^a
395	1.5±0.47 ^a	0.1±0.10 ^a	6.1±3.60 ^a	0.9±0.79 ^a	6.2±2.76 ^a	0.4±0.17 ^a
435	3.4±1.17 ^b	0.1±0.05 ^a	10.1±7.65 ^a	1.5±1.23 ^a	8.7±3.63 ^b	0.5±0.25 ^a
445	3.3±1.29 ^b	0.1±0.06 ^a	11.4±8.53 ^a	1.6±1.53 ^a	8.7±2.35 ^b	0.5±0.25 ^a
470	3.7±1.11 ^b	0.1±0.07 ^a	9.7±5.65 ^a	1.5±1.32 ^a	6.2±1.78 ^a	0.5±0.23 ^a
490	3.3±1.35 ^b	0.1±0.07 ^a	7.7±4.86 ^a	1.5±1.35 ^a	0.9±0.63 ^c	0.5±0.22 ^a

Refer to Table 1 for foot notes

1.511 % to 0.093 %, about a 10 fold decrease (Tables 1 and 2). This again resulted in the detection levels being statistically similar after cleaning irrespective of the wavelength used on a given surface treatments.

The detection of apple residue before cleaning on the three surfaces has been shown (Table 3). Detection on aluminium was most sensitive at wavelengths from 365 to 445 nm with no significant difference between the wavelengths in the range ($p < 0.05$) (Table 3). There was no significant difference between the 365–470 nm wavelengths in their sensitivity at detecting apple residue on the FRP, while detection sensitivity for apple residue on stainless steel before cleaning was significantly higher between 365 and 445 nm than at 470–490 nm (Table 3).

Detection of mango residue on aluminium before cleaning was most sensitive at 435–445 nm, being higher also than detection at 365–395 nm though not significantly different. Sensitivity at 470 nm on aluminium was significantly higher than at 490 nm (Table 4). On the FRP, mango detection was most sensitive at 395–445 nm, with no significant difference between the wavelengths in the range. Differences between the detection sensitivity at 365 nm and 470 nm were not significant though both were significantly more sensitive than 490 nm for mango on FRP before cleaning. The detection sensitivity for mango residue on stainless steel before cleaning was significantly higher between 365 and 445 nm than at 470–

490 nm (Table 4). Salo et al. (2008) observed that a UV lamp with wavelength 366 nm was effective at observing beer-based soil mixed with riboflavin inside stainless steel beer tanks.

The cleaning system applied significantly removed the apple residues present on the surfaces. For instance, the average area covered by apple residue on FRP detectable at 365 nm for instance was reduced from 18.15 % to 0.300 %, over 100 fold reduction while for mango residue under similar parameters the reduction was from 2.0481 % to 0.110 %, about a 20 fold decrease (Tables 3 and 4). However, there were clear differences in the sensitivity of the wavelengths to detect traces of residue present after cleaning. The 365 and 395 nm wavelengths were significantly more sensitive at detecting traces of apple and mango residue after cleaning on aluminium and stainless steel than the other wavelengths. For FRP, the difference after cleaning was significant between 365 and 445 nm as one group and 490 nm in another group.

Skim milk residue detection on the 3 surfaces is shown (Table 5). There was no significant difference in detection between 365 and 445 nm on aluminium before cleaning, and also between 365 nm and 470 nm on the FRP. Detection of skim milk on stainless steel before cleaning was significantly higher at 365–445 nm than 470 nm, while being negligible at 490 nm (Table 5).

Table 3 Average percentage area per field view of material surfaces covered with apple residue before and after cleaning^x

Wavelength (nm)	^y Aluminium		FRP		Stainless steel	
	Before cleaning	After cleaning	Before cleaning	After cleaning	Before cleaning	After cleaning
365	^c 6.2±4.18 ^a	0.3±0.23 ^a	18.2±18.01 ^a	0.3±0.41 ^a	4.5±3.55 ^a	0.1±0.07 ^a
395	7.9±3.85 ^a	0.3±0.19 ^a	24.0±19.94 ^a	0.3±0.27 ^a	5.6±2.88 ^a	0.1±0.06 ^a
435	8.2±4.32 ^a	0.01±0.01 ^b	24.3±19.61 ^a	0.4±0.34 ^a	5.8±3.21 ^a	0.01±0.04 ^b
445	5.3±4.90 ^a	0.01±0.02 ^b	23.5±19.27 ^a	0.4±0.33 ^a	5.4±3.28 ^a	0.01±0.02 ^b
470	4.3±5.24 ^{a,b}	0.001±0.003 ^b	21.1±19.91 ^a	0.1±0.18 ^{a,b}	0.6±1.08 ^b	0.001±0.001 ^b
490	0.5±0.23 ^b	0.001±0.003 ^b	2.24±4.12 ^b	0.002±0.01 ^b	0.01±0.01 ^b	0.001±0.004 ^b

Refer to Table 1 for foot notes

Table 4 Average percentage area per field view of material surfaces covered with mango residue before and after cleaning^x

Wavelength (nm)	^y Aluminium		FRP		Stainless steel	
	Before cleaning	After cleaning	Before cleaning	After cleaning	Before cleaning	After cleaning
365	^c 8.8±5.12 ^{a,b}	0.4±0.13 ^a	2.1±1.94 ^{a,b}	0.1±0.15 ^{a,b}	0.4±0.50 ^{a,b}	0.1±0.09 ^a
395	9.1±5.12 ^{a,b}	0.4±0.24 ^a	3.4±2.47 ^a	0.2±0.17 ^a	1.2±1.08 ^a	0.1±0.09 ^a
435	11.0±5.89 ^b	0.04±0.06 ^b	3.7±2.38 ^a	0.2±0.17 ^a	0.9±1.25 ^a	0.01±0.02 ^b
445	10.6±5.97 ^b	0.02±0.04 ^b	3.7±2.85 ^a	0.2±0.17 ^a	0.6±0.98 ^{a,b}	0.008±0.02 ^b
470	5.0±5.69 ^{a,c}	0.01±0.01 ^b	2.1±2.23 ^{a,b}	0.1±0.12 ^{a,b}	0.03±0.07 ^b	0.002±0.006 ^b
490	0.1±0.12 ^d	0.001±0.002 ^b	0.03±0.06 ^b	0.002±0.003 ^b	0.002±0.006 ^b	0.001±0.003 ^b

Refer to Table 1 for foot notes

The cleaning system applied significantly removed the skim milk residues present on the surfaces with more than 10 fold reduction across the 3 surfaces. There were however significant difference for detection on FRP, with 365–445 nm significantly more sensitive than 490 nm; a difference of about 100 fold higher sensitivity. Detection of skim milk on stainless steel after cleaning was essentially only possible at 365–395 nm after cleaning (Table 5).

The differences in the sensitivity of detection on the three studied surfaces at the wavelengths and food residues evaluated, was evident in accordance to the results obtained. There was however no specific trend, with differences being dependent of residue type. The specific properties of the food contact surface materials affect the levels of residue that are retained on them before and after cleaning (Abban et al 2012; Verran and Whitehead 2006). Other properties of surfaces such as colour and reflecting ability may also contribute to the sensitivity of detection of various residues on these surfaces; however this was out of the scope of the present study. For composite environments as those described for cargo containers (Abban et al 2012), it is important to recognize these difference in the choice of UV wavelength during cleaning validation.

Differences between wavelengths for the same residue on given surfaces were also shown in this work to be specific to the particular residue, though it was generally observed that sensitivity of detection was lowest at 490 nm for most residues.

Cleaning generally reduced the extent of soiling on all surfaces and for all residues. Effective cleaning protocols using appropriate detergents that reflect the type of residue on the surface is essential for maintaining hygiene standards. Also, the use of detergents with non-residual components that could remain on the surface after cleaning should be avoided, alongside ensuring adequate rinsing of surfaces (Gibson et al. 1999).

Comparison between residues for the various wavelengths showed that some particular wavelengths were optimal for a particular surface for a range of residues both before and after the cleaning step. For instance, the 395 nm wavelength produced optimal detection for beef, apple, mango and skim milk on aluminium surfaces after the washing step, with average values of 0.184 %, 0.304 %, 0.380 % and 0.225 % respectively, while detection levels before cleaning were either the highest at this wavelength or not significantly different from the highest values reported on aluminium (Tables 1, 2, 3, 4 and 5). For the chicken residue, though detection at 395 nm was the highest after cleaning at 0.101 % on average, detection level before cleaning were not among the highest for aluminium. Whitehead et al (2008) also observed differences in the ability of UV wavelengths at detecting different residues on stainless steel. Based on such comparison, a summary of the most sensitive wavelengths for the various residue/material surface combinations for the wavelengths used in this study is shown (Table 6).

Table 5 Average percentage area per field view of material surfaces covered with skim milk residue before and after cleaning^x

Wavelength (nm)	^y Aluminium		FRP		Stainless steel	
	Before cleaning	After cleaning	Before cleaning	After cleaning	Before cleaning	After cleaning
365	^b 7.6±0.76 ^a	0.2±0.33 ^a	12.2±10.59 ^a	0.2±0.20 ^{a,b}	7.8±2.13 ^a	0.1±0.09 ^a
395	7.3±0.94 ^a	0.2±0.45 ^a	15.5±13.25 ^a	0.2±0.21 ^a	6.5±1.82 ^{a,c}	0.1±0.08 ^a
435	7.4±0.81 ^a	0.02±0.05 ^a	17.2±13.14 ^a	0.2±0.21 ^a	7.3±1.93 ^a	0.001±0.001 ^b
445	7.7±1.18 ^a	0.03±0.08 ^a	22.6±15.36 ^a	0.2±0.23 ^a	7.6±1.72 ^a	0.0003±0.001 ^b
470	6.0±1.00 ^c	0.01±0.04 ^a	11.4±11.85 ^a	0.1±0.19 ^{a,b}	5.5±1.29 ^c	0.0002±0.001 ^b
490	0.002±0.003 ^b	0.01±0.02 ^a	0.2±0.71 ^b	0.002±0.002 ^b	0.004±0.01 ^b	0.0001±0.001 ^b

Refer to Table 1 for foot notes

Table 6 Most sensitive wavelength ranges for UV lamps to be used for detection of tested residue/material surface

Material surfaces	Most sensitive wavelengths (nm) for detecting studied residue				
	Beef	Chicken	Apple	Mango	Skim milk
^a Aluminium	365–445 (395) ^b	435–490 (435)	395–435 (395)	365–445 (395)	365–445 (395)
Fiber re-enforced plastic (FRP)	435–470 (435)	435–470 (445)	395–470 (435)	395–445 (435)	365–445 (445)
Stainless steel	365–445 (395)	435–445 (435)	365–445 (395)	395–435 (395)	365–445 (365)

^a Material surfaces used in the study: aluminium (alloy 5754), FRP fibre re-enforced plastic [Maersk Container Industry (MCI), Tinglev, Denmark], stainless steel (alloy 304)

^b Optimal wavelengths are in parenthesis; based on comparison of data and statistics from Tables 1, 2, 3, 4 and 5

From the results of this work, it is important that the optimal wavelength (band) is available from the UV-lamp to ensure proper evaluation in hygienic applications. The extent of detection at a given wavelength was dependent of both the residue and the contact surface material. This is particularly important in applications where multiple material types serve as (incidental) food contact surfaces, as is common in cargo containers. UV lamps have been reportedly used for validation of plastics and stainless steel surface in a cheese dairy where detection was easier on stainless steel than on the plastics, due in part to ‘reflection’ of light by some plastic materials (Förnäs 2006). However experienced users could still make accurate observations (Förnäs 2006). The commonest UV lamps on the market emit optimally at 365 nm (Whitehead et al. 2008; Verran et al. 2010). Thus the differences in ability to observe residue could be eased if a lamp with the right wavelength is used given the surface and residue. The ability to detect residue on cleaned surfaces is important since such soils are important in the adhesion and retention of microorganisms, which is also the starting point for the development of biofilms (Palmer et al. 2007).

One limitation from the results in this work was the high standard deviations in the average values reported, due mainly to the fact that the spread of food residues on the material surfaces was not uniform. Since the microscope used can only take images per field view, multiple random field views (15) were imaged per coupon in two independent repeat experiments. The application of the results and interpretation given should thus be done with this in mind.

In conclusion, our results show that different surface materials (other than stainless steel) may give different results as regards even the same kind of residue when particular UV wavelength or bands are used in detecting them. It might be important to find a ‘compromise’ wavelength band at which illumination is fairly visible even at low concentrations when evaluating an area with multiple surface material types. Alternatively one can change filters on the lamp so that alternative wavelengths suitable for the various material surfaces are also used. This will ensure that residues on different

material surfaces could be better visualized and thus the confidence in the validation of the surface hygiene is increased. Further work with other surface materials and residues specific to other environments may be required for given applications. Future work should also explore ways to evenly spread residue on the test surfaces to reduce the standard deviations, as well as working with mixtures of residues which is very likely in real case scenarios.

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