ABSTRACT

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NONINVASIVE CLEANING AND SANITATION MONITORING SYSTEM FOR DELI DEPARTMENT PROCESSING

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The inability to adequately judge the efficacy of cleaning/sanitation in deli departments is a recognized food safety concern. In prior studies, our research group demonstrated that visual inspection of cleaned produce processing surfaces could be enhanced through the use of a portable imaging device. To explore the feasibility of using this technology to facilitate detection of deli residues, fluorescence spectra of deli commodities were acquired using a laboratory-based hyperspectral imaging system. Cheeses evidenced a strong response at 675 nm; meats were best detected at 475 or 520 nm, demonstrating these wavelengths are good candidates for deli residue detection. To confirm these findings, images were taken of an in-house deli slicer with the portable imaging device. Deli residues were detected and several slicer areas were identified as

being prone to residue buildup. Results confirmed the potential to use a portable imaging device to enhance current cleaning procedures in a deli setting.

NONINVASIVE CLEANING AND SANITATION MONITORING SYSTEM FOR DELI DEPARTMENT PROCESSING

By

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Chapter 1: Introduction

Food safety is a top priority in the food industry. Ready-to-eat (RTE) foods including fresh deli commodities pose a high risk for causing foodborne illness. For example, deli meats are recognized as the leading cause of listeriosis in the United States, causing an estimated 1,600 illnesses per year and accounting for roughly 64% of all U.S. listeriosis cases every year (USDA FSIS 2010a). Furthermore, when compared to prepackaged deli meats, freshly sliced meats from a retail facility account for approximately 83% of deli meat listeriosis cases, causing approximately 167 deaths per year (USDA FSIS 2010a). A 2011 study by FDA's Center for Food Safety and Applied Nutrition, CFSAN, found contamination of deli meats and cheeses to be a major concern and placed culpability on the cleaning and sanitation of commercial equipment, including deli slicers (CFSAN 2011a, CFSAN 2011b). Additionally, a draft version of an interagency risk assessment for *Listeria monocytogenes* in retail delicatessens was published on May 1, 2013 identifying the deli slicer as a source of *Listeria monocytogenes* cross-contamination. The agencies are urging retail deli personnel to improve food safety practices. Agencies that joined together to work on this risk assessment includes: the United States Department of Agriculture Food Safety and Inspection Services (USDA FSIS), FDA CFSAN, the Centers for Disease Control and Prevention (CDC), and the Department of Health and Human Services (DHHS) (Akingbade 2013).

Current sanitation verification in deli departments is primarily based on visual inspection. This technique allows for a broad inspection of food-contact surfaces in real

time, but cannot appropriately verify cleaning and sanitation. Alternative techniques for verification include ATP testing and culturing for pathogen detection; while these methods are more sensitive than visual inspection, they only focus on a subset of the surfaces in the deli. An ideal technique for verification would cover a large surface area in real time, while also providing the sensitivity to detect food residues, a nutrient source for bacteria and a contaminant itself, at a level not easily visible with the naked eye. One potential solution to address this need might be to use imaging technologies to allow a more sensitive examination of deli equipment and surfaces. It has been demonstrated that visual inspection of cleaned surfaces in produce processing plants can be enhanced through the use of a portable imaging device (Wiederoder 2011). This study explored the feasibility of using this imaging technology to facilitate detection of deli residues left post-sanitation in deli departments.

Chapter 2: Literature Review

Introduction

Foodborne illness is one of the primary concerns in the area of food safety; millions of Americans every year fall ill from contaminants in the food they eat. One major area of concern is with ready-to-eat (RTE) products, because there is generally no further intervention such as cooking prior to consumption. Deli commodities fall into this category and have had trouble with foodborne illness outbreaks in the past. Commodity handling, cleaning and sanitation, and monitoring procedures are in place to reduce the instance of contamination. However, there is a well-recognized need to enhance cleaning and sanitation monitoring, and imaging technology has the potential to provide a solution.

The CDC estimates that one in every six Americans contracts a foodborne illness every year, causing an annual economic loss of $77 billion (CDC 2012, Scharff 2011). Among these 48 million Americans, 128,000 are hospitalized and 3,000 die (CDC 2012). Anyone can fall victim to foodborne illness, however, there are four main high-risk groups that are more likely to suffer serious complications: young children, the elderly, pregnant women, and immunocompromised individuals (USDA FSIS 2011a). Foodborne illness originates from the consumption of a contaminated food product, which could be contaminated by a number of pathogens including but not limited to: bacteria, yeasts, molds, viruses, or parasites. Some of the top pathogens contributing to a high frequency of foodborne illness include *Norovirus* and *Salmonella*, while the deadliest include *Salmonella* and *Listeria monocytogenes* (CDC 2012).

RTE foods are at particular risk in terms of foodborne illness outbreaks. As the name describes, RTE foods is a category of products that are ready for consumption upon purchase without the intervention of a cooking step to eliminate pathogens; therefore, RTE foods pose a greater risk of causing foodborne illness than commodities with a lethal process (e.g. heat) post purchase.

Over the past five years, deli departments have seen an increase in variety and product demand. Consumers continue to seek out convenience with their grocery purchases, leading to increased purchases of RTE products (Zagorski 2011). This is true for deli commodities such as freshly sliced meats and cheeses. Within the aforementioned timeframe, specialty cheeses have seen a 12.5% increase in sales dollars (Gritti 2012). Deli subgroup, freshly-sliced meat, has also seen a measured increase in dollar shares for its category, now leading the deli meat sales with 86% of the dollar share, versus prepackaged meats' 14% dollar share (Matzen 2010). With deli commodities' growing popularity, food safety remains a main focus. Deli department sanitation plays a key role in reducing the risk of selling contaminated products. Improper cleaning and sanitation has lead to delis being troubled with foodborne outbreaks in the past (Abercrombie et al. 2007, BCCDC 2009, CDC 2010, CDC 2011a/b, Falkenstein 2011, Powell 2007, USDA FSIS 2010b/c, and USDA FSIS 2011b). As outlined in the table below, recent outbreaks in the deli industry, especially those involving *Salmonella* and *Listeria monocytogenes,* highlight the need to improve deli sanitation and sanitation verification (Table 1).

Table 1 Recent foodborne outbreaks associated with deli commodities.

Microorganism	Product	Outbreak	Year	Reference
E. coli 0157:H7	Various Cheeses	Recall, multistate, 35 illnesses, 15 hospitalizations, 1 HUS	2010	CDC 2011a
	Lebanon Bologna	Class 1 recall, Multistate, 14 cases	2011	CDC 2011b, USDA FSIS 2011b
Listeria monocytogenes	Various Cheeses	Recall, multistate	2010	CDC 2011a
	Pastrami, Roast Beef	Recall, no retail sales	2011	Falkenstein 2011
	Roast & Corned Beef, Deli Meats	Recall, 5 cases, 2 deaths	2008	BCCDC 2009
	Various Deli Meats	Recall, 50 illnesses, multistate, 6 deaths	1998-1999	CDC 1999
Salmonella montevideo	RTE Italian Sausages	Class 1 recall, Multistate, 272 cases	2010	USDA FSIS 2010b, USDA FSIS 2010c, CDC 2010
	Roast Beef	11 cases, deli slicer	2006	Powell 2007
	Roast Beef	72 cases, deli slicer	2007	Abercrombie and others 2007

Deli Department Commodity Handling Procedures

Deli departments establish handling procedures in part to help prevent
contamination and illness. Employees frequently handle commodities throughout the
day; therefore, an important step in preventing contamination is focused on employee
hygiene. Proper hygiene techniques include: frequent hand washing, using hand
sanitizers and disposable gloves, wearing clean clothing/aprons, and restraining or
covering hair (USDEC 2005). Employees should be especially cautious when handling
raw food items and cleaning equipment that comes in contact with raw food items.

Segregation of certain commodities will also reduce cross-contamination risks. Due to live bacterial activity in cheeses, meats and cheeses should be sliced on separate deli slicers (USDEC 2005). Bacteria beneficial to cheeses can be detrimental to deli meats, causing problems from off odors to more rapid microbial spoilage (USDEC 2005). Also, if any raw products are stored in the deli area, they should be kept separate from and stored below all cooked products. This will reduce the risk of raw meat drippings falling onto finished product.

Another important component of commodity handling is maintaining proper storage temperatures. Cold foods need to be kept cold and hot foods need to be kept hot. Table 2 shows a commonly used temperature table for deli commodities. Note, these ranges avoid the "Danger Zone", 40-135°F, which allows for rapid multiplication of bacteria (USDEC 2005).

Table 2 Suggested temperature regulations for deli commodities (USDEC 2005).

Area	Temperature Range
Storage Freezer	$\leq 0^{\circ}$F
Storage Refrigerator	30-40°F
Display Case Refrigerator	30-40°F
Hot Holding Temperature	$\geq 135^{\circ}$F

Current Cleaning and Sanitation Procedures

Cleaning and sanitation plays a key role in food safety; methods include the cleaning and sanitizing of food-contact and non food-contact surfaces. Food contact surfaces should be visibly free of debris before every use and should be cleaned every

four hours (USDEC 2005). One important food contact surface is the deli slicer, which should be wiped down after every use with a sanitized cloth to remove large food particles from the slicing surface. The slicer should also be thoroughly cleaned by washing with detergent and sanitizing on a regular basis (USDEC 2005).

Counter tops, cutting boards, and other prep-work surfaces are required to be washed and sanitized on a daily basis. These surfaces are important points of concern with cross-contamination because a large variety of commodities come in contact with these surfaces throughout the course of the day. There should also be sanitizer available for sanitizing throughout the day if required (USDEC 2005).

Most other areas of the deli require less frequent sanitation. Utensils should be cleaned and sanitized at the end of every day or more frequently for reuse. Floors should be swept clean and sanitized at the end of every day, and spills should be cleaned up immediately. Display cases should be cleaned as stated by the case manufacturer (USDEC 2005). Cleaning and sanitation measures are verified through the use of sanitation monitoring techniques.

Sanitation Monitoring

There are three main methods of validating the cleaning and sanitation procedures in the food industry: culturing techniques, ATP bioluminescence assays, and visual inspection. An ideal monitoring technique would be able to survey a large surface area while providing a real-time, sensitive analysis.

Culturing techniques are split into two main categories and can be used to determine the presence of specific pathogens on a surface. First, for traditional culturing,

a surface area is swabbed and streaked onto a selective media. The plate is then incubated, and colonies are counted. Depending on initial results, a series of plates and media may be needed to confirm the presence or absence of a pathogen. It can take over a week to gain confirmatory results (USDA FSIS 2012). The second culturing technique is the use of Petrifilm plates for rapid detection of organisms. Petrifilm plates require no plate preparation and generally require just a serial dilution for sample preparation. Petrifilm can be utilized for many indicator organism and pathogen testing (3M 2013). The main advantages of Petrifilm over regular culturing techniques are ease of plate/sample preparation and more rapid results. Petrifilms can produce results in as little as six hours (3M 2013). While culturing techniques can be quite sensitive and provide information about the presence of pathogens, there are a number of disadvantages when using this technique to monitor cleaning and sanitation procedures. Culturing techniques require a skilled lab technician to run the testing, only look at a small sampling area, require a longer lag time for results compared to other methods, and have reoccurring costs for testing supplies.

Adenosine triphosphate (ATP) is a compound produced by all living cells, making it a compound representative of organic material and potential microbial contamination. During an ATP bioluminescence assay, ATP from a swabbed surface is combined with luciferin/luciferase in a magnesium buffer; which causes a photon emitting reaction (Chen 2006, Lo and others 2010). These photons are measured by a luminometer and quantified in relative light units (RLUs). The greater the RLU response, the more ATP is present on the surface (Chen 2006). Using a commercial ATP bioluminescence assay, a surface is sampled with a swab containing reagents and inserted into a handheld reader;

which can provide results within seconds or minutes, depending on the device sophistication (Costa 2006). One benefit to ATP testing over culturing is that using an ATP assay can show the presence of ATP, not just microbes. However, ATP bioluminescence assays have inherent disadvantages similar to culturing techniques, they allow for only small sampling areas and they have the reoccurring expense of swabbing supplies. In addition, an ATP assay may detect dead bacteria.

To date, visual inspection is the main method of cleaning and sanitation verification. This technique is inexpensive because it does not require any test supplies or equipment; also, it allows for a real-time analysis of a large surface area without recurring costs for sampling materials. Employee eyesight is the primary limiting factor for contaminant detection. However, many contaminants are not visible or not easily recognized using visual inspection, small pieces of organic debris, leaving many contaminants undetected.

Imaging

Hyperspectral imaging combines spectrometry with spatial visualization. Hyperspectral data is generally stored in a 3-dimensional data cube with two physical and one spectral dimension (Chang 2013). Data can be acquired using two techniques. For line-scan imaging, acquired images have one spectral and one physical dimension; the second physical dimension is produced by taking sequential images as the object of interest is moved in a stepwise manner through the imaging field. Alternatively, photo-like images can be acquired at selected wavelengths using the appropriate optical filters. Different information can be extracted from hyperspectral data, depending on what is of interest. A method of identifying a small subset of relevant wavelengths can allow for a

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rapid, simpler method for image processing. A recent study using hyperspectral imaging

to detect produce residue in a fresh-cut produce plant environment, used a subset of

individually analyzed wavelengths for rapid detection of potential points of

contamination (Lefcourt 2013, Wiederoder 2011, Wiederoder 2013)

Ambient light interference can be a critical factor when collecting hyperspectral

imaging data. For example, reflected light from ambient illumination can completely

obscure a fluorescence response at a wavelength of interest. Deli departments commonly

use fluorescence lighting and, for employee safety, lighting cannot be fully turned off for

imaging (Rensselaer Polytechnic Institute 1994). Known gain peaks for fluorescent

lighting are 485-495, 535-555, 575-635, and 690-715 nm (Wiederoder 2011). These

ranges should be avoided when choosing wavelengths for fluorescence imaging

detection. Figure 1 shows a typical profile of gain adjustments by wavelength for a

portable hyperspectral imaging device in a fluorescence lighting setting. Gain peaks

occur at wavelengths where ambient light intensities are low, while gain minima are

associated with higher ambient light intensities. Interference from ambient lighting can

be reduced by selecting detection wavelengths near gain peaks. Potential ranges include:

450-480, 505-530, 560-570, and 640-685 nm. A prior study using the portable

hyperspectral imaging system used in this study found that the wavelengths of 475, 520,

and 675 nm will optimal for detecting residues remaining after cleaning and sanitation in

fresh cut processing plants (Lefcourt 2013, Wiederoder 2011, Weideroder 2013).
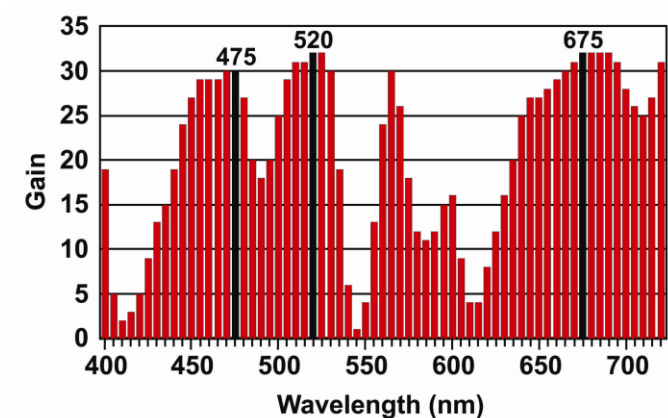
Hyperspectral imaging has been studied in numerous areas of the food industry over recent years. Below, are examples of some recent studies (Table 3).

Table 3 Examples of recent used of imaging technology in the food industry.

Field	Concentration	Imaging Technology	Reference
Apples	Bovine fecal contamination detection	Hyperspectral reflectance and fluorescence	Kim 2007
	Defect detection	Hyperspectral fluorescence	Mehl 2003
Cherry Tomatoes	Defect detection	Hyperspectral fluorescence	Cho 2013
Chickens	Carcass skin defect	Hyperspectral fluorescence	Kim 2004
	Fecal contamination	Hyperspectral-multispectral line-scan imaging	Chao 2007
Fresh-Cut Produce	Produce production residue	Hyperspectral fluorescence	Lefcourt 2013, Wiederoder 2011, 2013

Summary

Deli departments have seen a rise in product sales over the past five years. With this increase in sales, comes an increase in concern for food safety. Recent foodborne illness outbreaks in the deli industry demonstrate a need for better cleaning and sanitation verification procedures. While, in theory, culturing techniques and ATP testing can

detect the presence of surface contamination, visual inspection remains the main

technique used for cleaning and sanitation verification in deli departments. Visual

inspection can survey a large area in real time, but it does not provide the level of

sensitivity needed to effectively monitor the cleanliness of a deli department. A proposed

solution is the use of a portable imaging device to enhance current verification methods

to reduce the risk of deli-related foodborne illness outbreaks.

Chapter 3: Research Goals & Objectives

The overall goal was to explore the feasibility of using imaging technology to enhance cleaning and sanitation verification procedures in deli departments. The main focus was the detection of deli commodity residues on food contact surfaces. A laboratory based line-scan hyperspectral imaging system was used to determine a minimal subset of wavelengths needed for detection of residues and a portable imaging device was used to survey deli slicer surfaces for subsequent residue detection.

Objectives

Objective 1.   To explore the feasibility of using imaging technology to facilitate detection of deli residues on food contact surfaces. Specific commodities of interest include deli meats and cheeses; specific surfaces of interest include stainless steel (SS) and high-density polyethylene (HDPE).

Phase I- Spectral characterization of deli commodities

Phase II- Changes in spectra with brand and time

Objective 2.   To test the use of a portable imaging device for real-time deli department sanitation verification. Specific interests include deli slicer surfaces.

Phase III- Deli slicer contamination detection

Justification

1. RTE foods, including deli commodities, pose a high risk of causing foodborne illness

2. The ability to adequately judge the efficacy of cleaning and sanitation in deli departments is a recognized food safety concern

3. Current verification techniques lack a sensitive, real-time, large surface area technique for detecting residues

Chapter 4: Spectral Characterizations

Introduction

This chapter addresses the feasibility of using imaging technology to facilitate detection of deli residues on food contact surfaces. In Phase I, spectra of selected deli commodities were determined and a potential subset of wavelengths that allowed for detection of all commodity residues was identified. In Phase II, changes in spectra over time were explored.

Phase I- Spectral Characterization of Deli Commodities

Materials and Methods

Samples of deli commodities were placed on stainless steel (SS) and high-density polyethylene (HDPE) coupons. A laboratory based line-scan hyperspectral imaging device with violet-405 nm light and white light excitation was utilized to determine the fluorescence and reflectance spectra of the samples, respectively. Images were analyzed using in-house software.

Coupon Preparation

SS and HDPE coupons were cut by a local business into 90 mm x 40 mm rectangles; SS coupons were buffed with steel wool to reduce surface imperfections. SS and HDPE coupons were washed with soap and water, rinsed with distilled water, and then allowed to air-dry. Each coupon was used only once.

Sample Preparation

Slices of cheeses (American, cheddar, provolone, and Swiss) and meats (chicken, ham, roast beef, and turkey) were acquired from the deli departments of local grocery stores. These commodities were selected because of their popularity and, therefore, common contact with the deli slicer. All commodities were sliced to similar thickness (~5 mm) and used on the same day as purchase. The first and last slices of each deli commodity were discarded. Using the middle slices, a cork borer was used to bore 2.5 mm radius punches. Thirty-two replicate punches were placed on each coupon. One stainless steel and one HDPE coupon was prepared for each commodity.

In addition, two coupons (one SS and one HDPE) were prepared combining all cheese types (Figure 2, Table 4). Two coupons (one SS and one HDPE) were prepared combining all meat types (Figure 3, Table 5). Eight samples of each commodity type were placed on the coupons to randomize potential intensity differences due to sample positioning. The cork borer was wiped free of debris and rinsed with water between each commodity sampling.
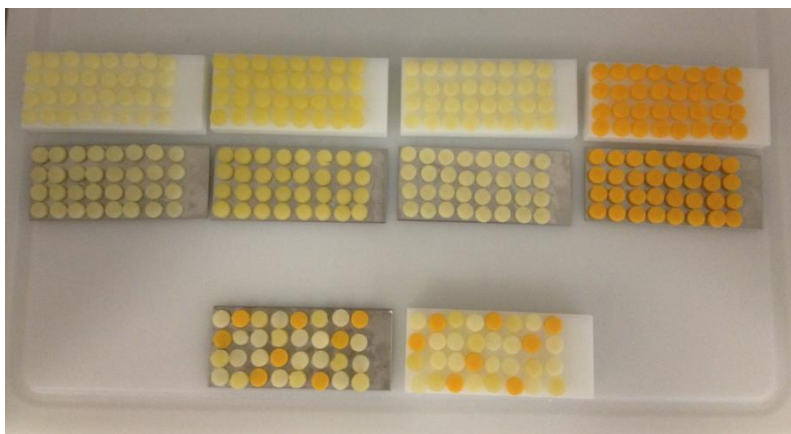
Figure 2 Cheese samples on HDPE (top and bottom right) and stainless steel (middle and bottom left) coupons. Single commodity coupons from left to right: provolone, Swiss, American, cheddar; bottom row: mixed commodity coupons.
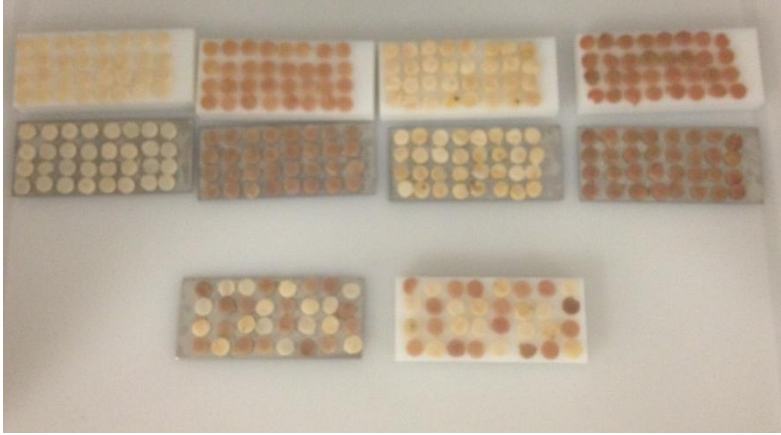
Figure 3 Meat samples on HDPE (top and bottom right) and stainless steel (middle and bottom left) coupons. Single commodity coupons from left to right: turkey, ham, chicken, roast beef; bottom row: mixed commodity coupons

Table 4 Placement of cheese samples on mixed commodity coupons.

	1	2	3	4	5	6	7	8
1	Swiss	Provolone	Cheddar	Swiss	American	Cheddar	Swiss	Provolone
2	Provolone	Swiss	Provolone	American	Cheddar	American	Provolone	Swiss
3	American	Cheddar	American	Provolone	Swiss	Provolone	American	Cheddar
4	Cheddar	American	Swiss	Cheddar	Provolone	Swiss	Cheddar	American

Table 5 Placement of meat samples on mixed commodity coupons.

	1	2	3	4	5	6	7	8
1	Roast Beef	Turkey	Ham	Roast Beef	Chicken	Ham	Roast Beef	Turkey
2	Turkey	Roast Beef	Turkey	Chicken	Ham	Chicken	Turkey	Roast Beef
3	Chicken	Ham	Chicken	Turkey	Roast Beef	Turkey	Chicken	Ham
4	Ham	Chicken	Roast Beef	Ham	Turkey	Roast Beef	Ham	Chicken

Hyperspectral Data Acquisition

A laboratory based line-scan hyperspectral imaging device with violet-405 nm light and white light excitation (Kim 2011) was utilized to determine the fluorescence and reflectance spectra, respectively, of the test samples on HDPE and stainless steel surfaces. The system consists of an electron-multiplying charge-coupled-camera

(EMCCD; MegaLuca R, ANDOR Technology, South Windsor, CT), an imaging

spectrograph (VNIR Concentric Imaging Spectrograph, Headwall Photonics, Fitchburg,

MA), a C-mount object lens (F1.9 35 mm compact lens, Schneider Optics, Hauppauge,

NY), two white light lamps (150 W DC quartz-tungsten halogen lamp coupled with a pair

of bifurcated fiber optic line lights (Fiber-Lite, Dolan-Jenner Industries, Inc., Lawrence,

Mass.)) for reflectance, and housing with two rows of 405 nm LEDs for fluorescent

excitation (Figure 4).
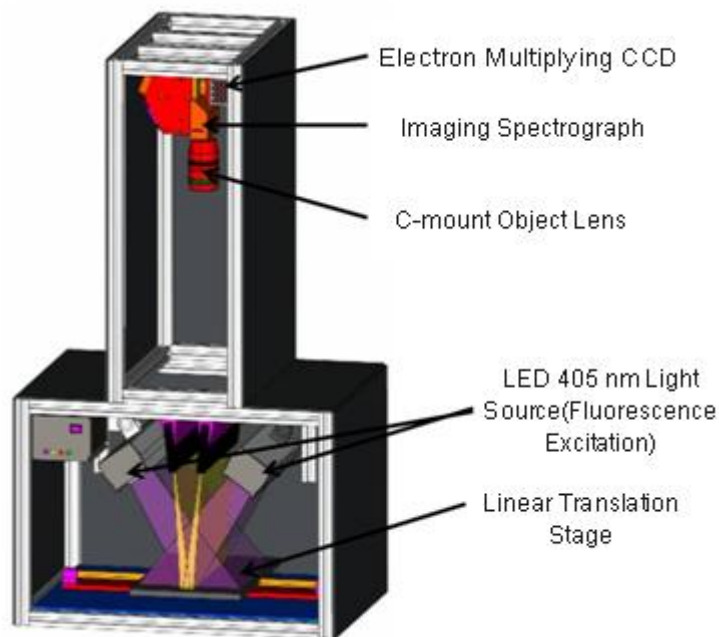
Figure 4 The laboratory based line-scan hyperspectral imaging device.

In-house software developed using Microsoft Visual Basic (Version 6.0,

Microsoft, Seattle, WA) was used for imaging system control, data acquisition, and

image processing. After allowing sufficient time for the excitation source to warm up (10

minutes), gain and exposure levels were set and each coupon was individually imaged for fluorescence responses. During scanning, a motorized positioning table moved a single coupon across the linear field of view in 0.5 mm increments. Wavelengths captured were at 3.94 nm intervals, which resulted in 85 bands.

Image Analysis

Thirty-two circular regions of interest (81 pixels) were automatically produced and manually placed on punches. A routine was then run to automatically center the regions of interest within the samples. As a control, three regions of interest (29 pixels) were produced and manually placed on the coupon surface. The location of the regions of interest and the average intensity data for each region of interest was saved for analysis.

Initially, for each single-commodity coupon, thirty-two replicate samples were graphed. Due to the uniformity of responses, the thirty-two regions of interest were averaged and graphed. For multiple-commodity coupons, the eight regions of interest for each commodity type were averaged and graphed. Additionally, all three control regions of interest were averaged for each coupon. As indicated previously, images for wavelengths 475, 520, and 675 nm were selected when viewing.

Results

Single Commodity Detection on Stainless Steel and HDPE Surfaces

On all single commodity coupons, all samples produced the same peaks and valleys with similar fluorescence intensity responses. For example, Figure 5 shows the fluorescence responses for 32 replicate samples from American cheese.

All cheese and meat commodities evidenced fluorescence responses with a higher intensity than SS and HDPE backgrounds at all measured wavelengths between 464-799 nm with violet-405 nm fluorescence excitation. The spectral pattern of the commodities remained the same on both SS and HDPE surfaces; however, with an HDPE surface as the background, amplitudes were generally higher. For example, Figure 6 and Figure 7 compare the fluorescence responses for American cheese on SS and HDPE surfaces. Additionally, Figure 8 and Figure 9 compare fluorescence responses for turkey on SS and HDPE surfaces.
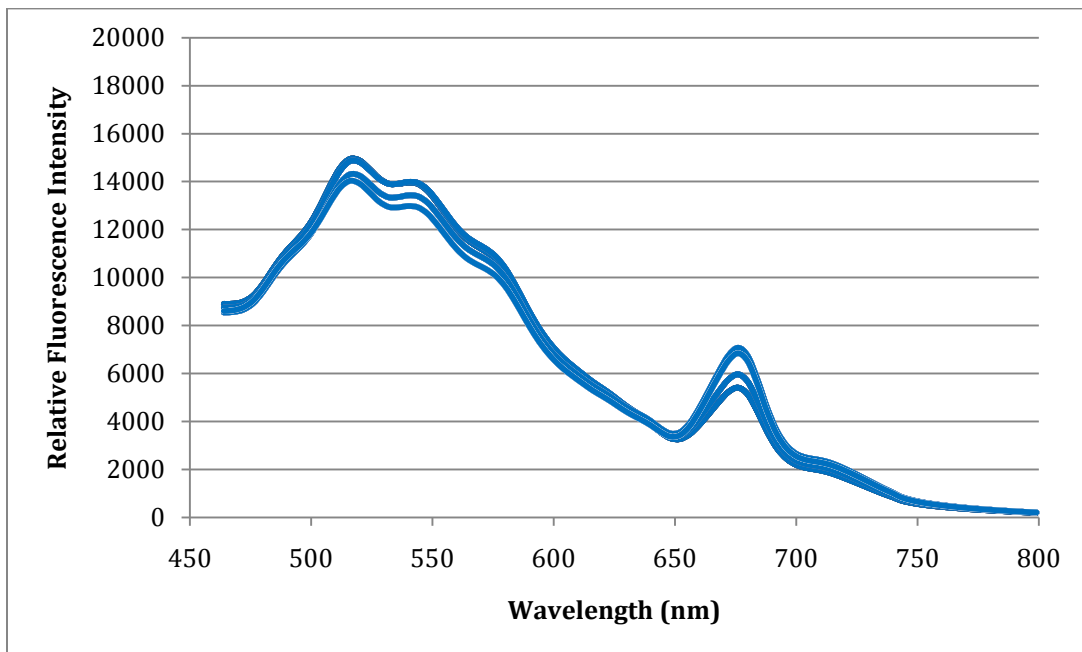
Figure 5 Relative fluorescence intensity of 32 replicates of American cheese (n=1) with violet-405 nm light excitation between measured wavelengths 464-799 nm on a stainless steel surface.
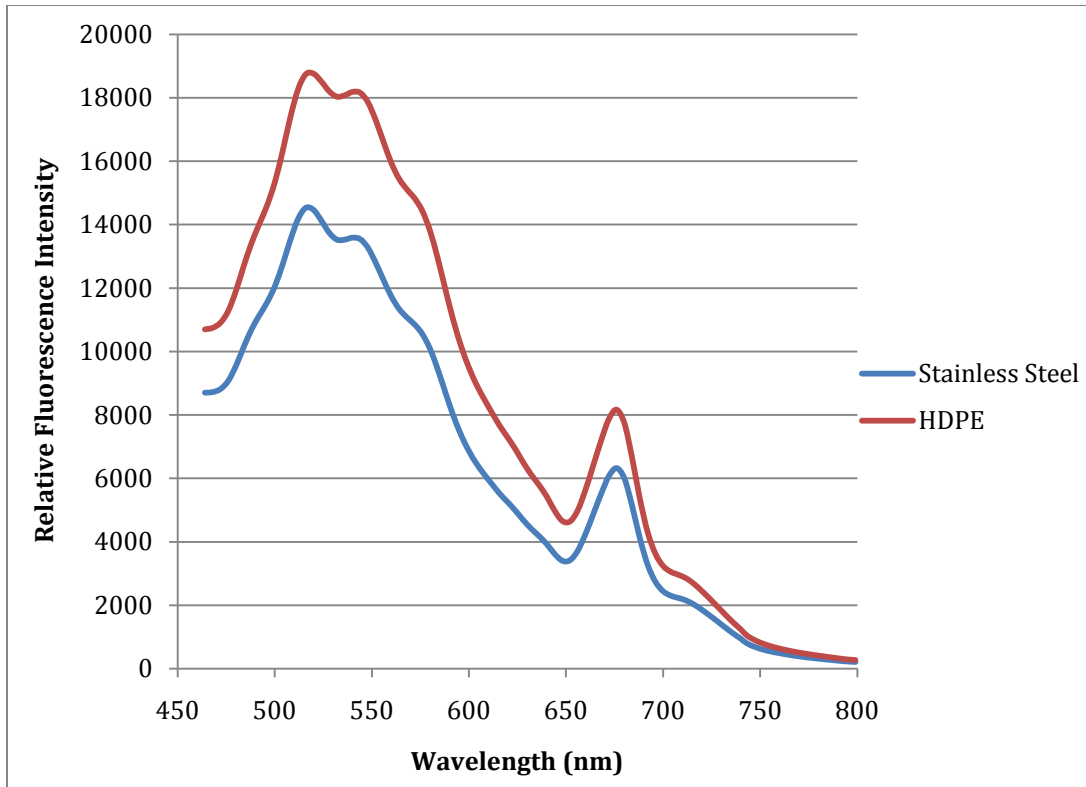
Figure 6 Relative fluorescence intensity of American cheese with violet-405 nm light excitation between measured wavelengths 464-799 nm on both stainless steel and HDPE surfaces (n=32).
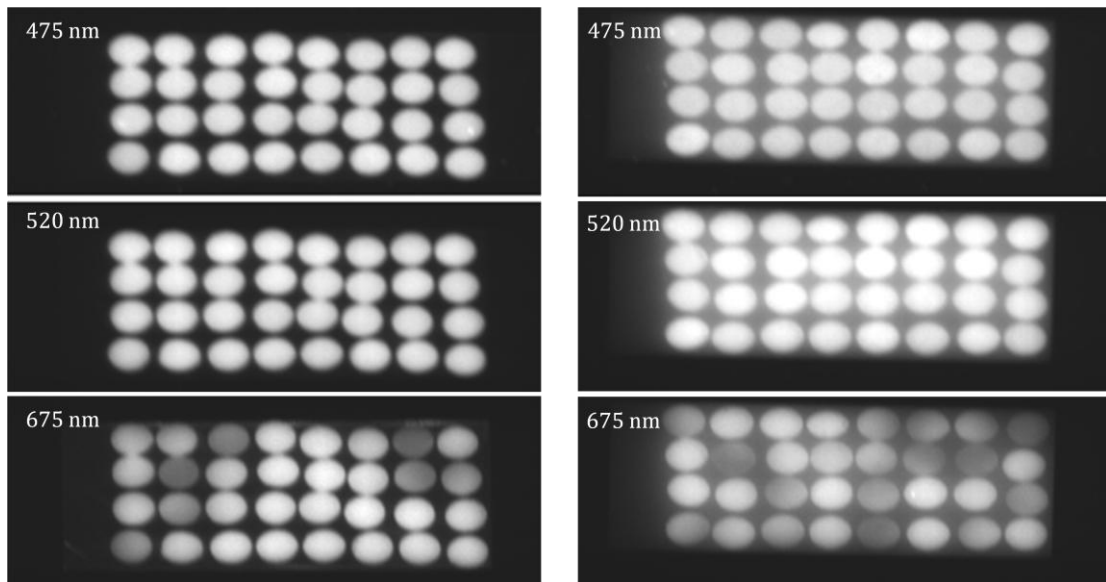
Figure 7 American cheese under violet-405 nm light excitation at selected wavelengths on stainless steel (left) and HDPE coupons (right). Fluorescence intensity variation between samples at 675 nm can be attributed to variation in homogeneity of the cheese.
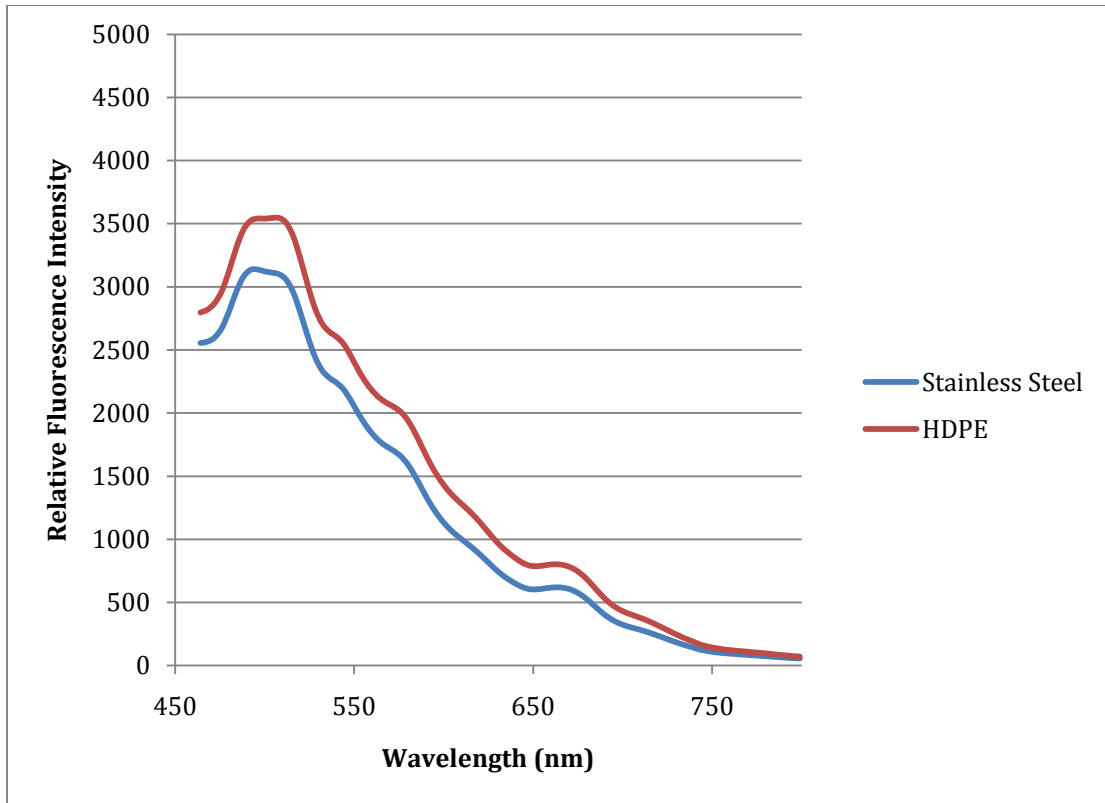
Figure 8 Relative fluorescence intensity of turkey with violet-405 nm light excitation between measured wavelengths 464-799 nm on both stainless steel and HDPE surfaces (n=32). Note differences in y-axis scaling.
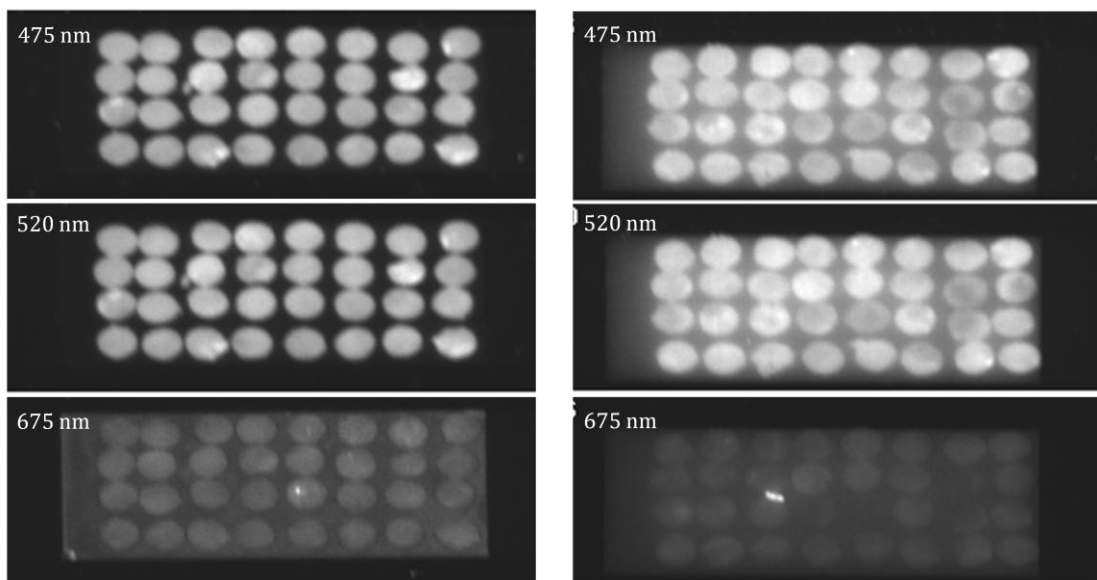
Figure 9 Turkey under violet-405 nm light excitation at selected wavelengths on stainless steel (left) and HDPE coupons (right).

Multiple Commodity Detection on Stainless Steel

All cheese types evidenced fluorescence responses above background on a single coupon at all measured wavelengths between 464-799 nm. Spectral characterization of all cheese types tested (American, cheddar, provolone, and Swiss) showed broad overlapping peaks between 520-550, 550-580, and 660-680 nm (Figure 10). American cheese evidenced the highest fluorescence response between the ranges 520-550 and 550-580 nm, while provolone cheese produced the strongest fluorescence response at 660-680 nm (Figure 10). Differences were noticeable in fluorescence images at different wavelengths as seen in Figure 12. At 475 and 520 nm, cheddar cheese samples produced a weak, dark fluorescence response; however, at 675 nm, cheddar cheese fluoresced with a much brighter response and a stronger fluorescence response than Swiss cheese.

All meat types evidenced fluorescence responses above background on a single coupon at all measured wavelengths between 464-799 nm (Figure 11). Spectral characterization of all meat types tested (chicken, ham, roast beef, and turkey) showed a broad overlapping peak between 480-520 nm (Figure 11). Visible differences in response were also seen with meat samples. Different types of meat showed stronger responses than others; for example, chicken showed the strongest response at both 475 and 520 nm, while roast beef showed the lowest response and is distinctly less visible in Figure 12.
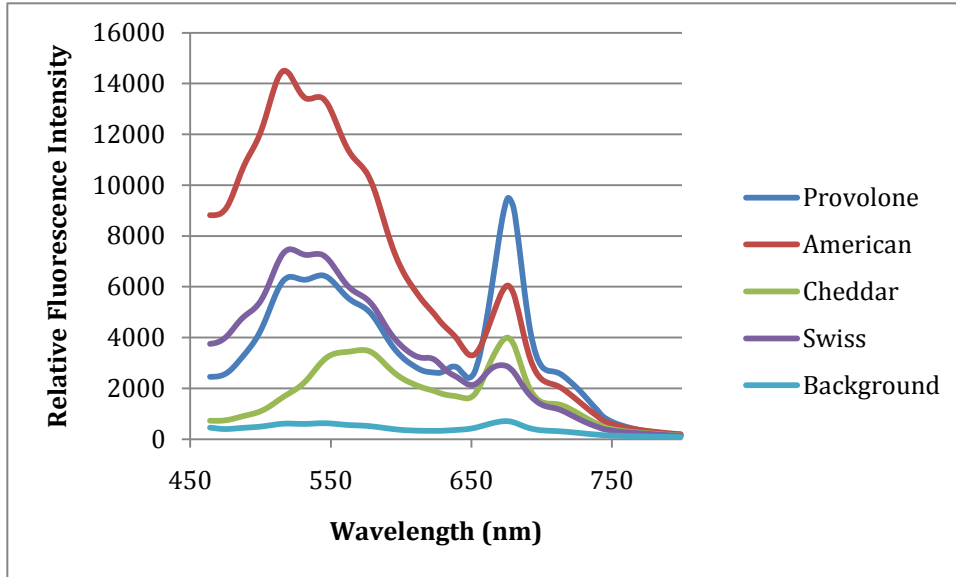
Figure 10 Relative fluorescence intensity of all tested cheeses with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=8).
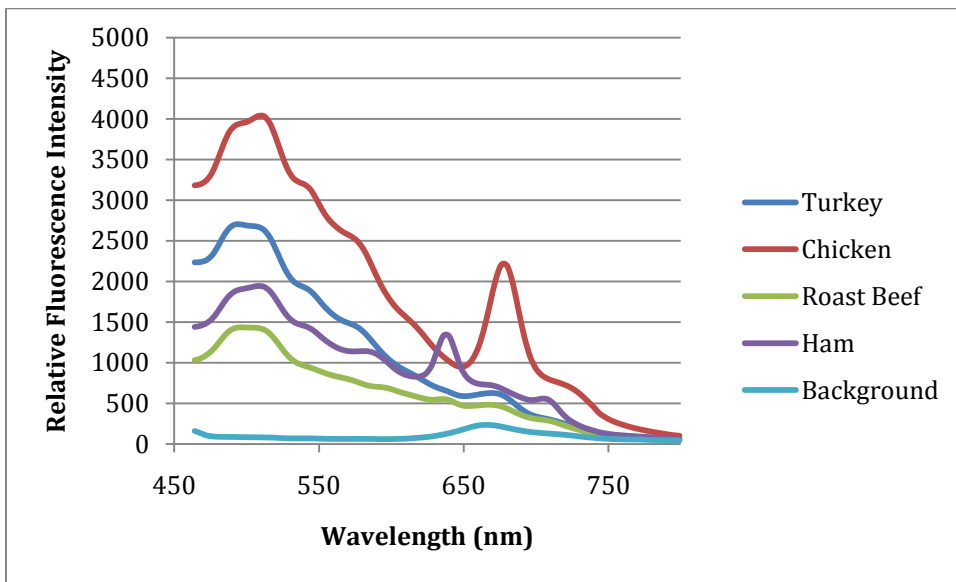
Figure 11 Relative fluorescence intensity of all tested meats with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=8). Note the y-axis change in scale from Figure 10.
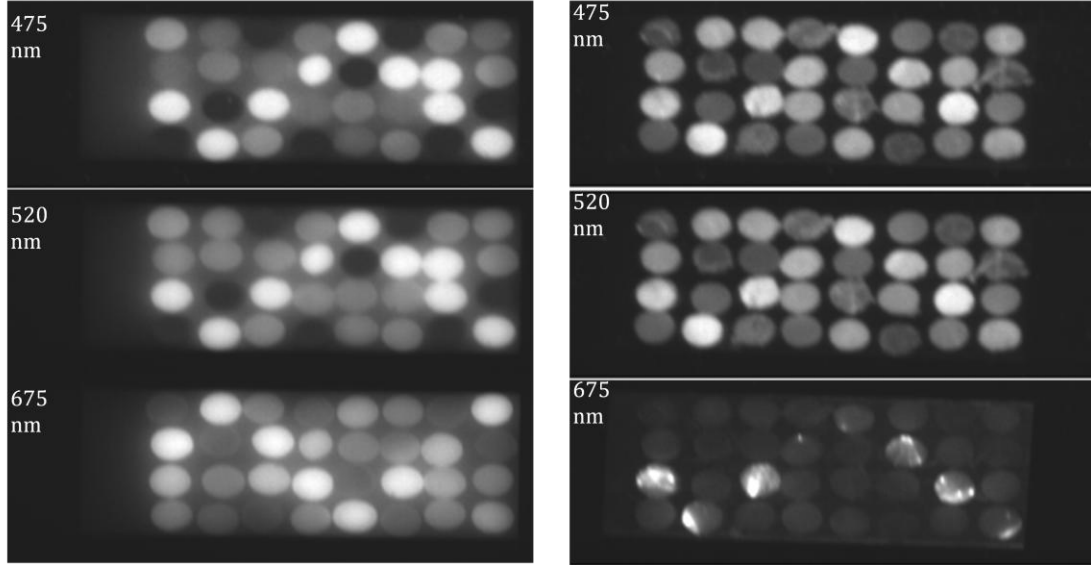
Figure 12 All cheeses on a stainless steel coupon (left) and all meats on a stainless steel coupon (right) under violet-405 nm light excitation at selected wavelengths. Reference Table 4 and Table 5 to identify sample type.

Discussion

With the use of hyperspectral imaging, deli commodities were detected above background at all wavelengths tested, and a minimal subset of wavelengths for reliable detection was identified. Based on phase one results, it is potentially feasible to use imaging technology to facilitate detection of deli residues on food contact surfaces.

All thirty-two replicates from a single-commodity coupon had similar spectral characteristics, which made it possible to average samples from the same commodity for further analyses. Amplitude of spectra differed depending on the background material; commodities evidenced higher fluorescence responses on an HDPE background compared to a stainless steel background (Figure 6, Figure 8). It is hypothesized that HDPE's own fluorescence response contributed to the detected response of samples,

which can be visualized in Figure 7 and Figure 9. Even though there were changes in amplitude, all deli commodities evidenced fluorescence responses with greater intensity than both stainless steel and HDPE background surfaces. As responses for SS and HDPE were similar, it was decided to use only SS coupons for Phase II studies.

With overlapping fluorescence intensity peaks, a subset of wavelengths could be used to detect commodities. When choosing the proper subset of wavelengths for detection, the effect of ambient lighting on the ability to detect fluorescence responses from deli commodities needed to be considered. Imaging will be done in low ambient light settings in deli departments, so the subset of wavelengths must be where ambient lighting evidences weaker fluorescence intensity responses, compared to other wavelengths between 464-799 nm. As seen in Figure 1, peaks in gain correspond to lower ambient light intensities. Previously, three wavelengths have been used successfully to survey produce plants: 475, 520, and 675 nm (Wiederoder 2013). Based on the fluorescence responses from deli commodities and previous studies on imaging in food processing, ambient light settings, 475, 520, and 675 nm were also chosen as the minimal subset of wavelengths for detection.

While all meats and cheeses could be detected above background, one wavelength is not appropriate for easy detection of all meat and cheeses. Cheeses showed varying responses at 475 and 520 nm, but did prove to be easy to detect all types of cheeses at once at 675 nm. On the other hand, meat samples were easily visible at 475 and 520 nm, but few showed a response at 675 nm. It should also be noted that cheeses produced higher relative fluorescence responses than meats; therefore, making cheeses, overall, easier to detect than meats (Figure 10, Figure 11).

One limitation with this experiment is that only a subset of deli commodities was analyzed. While there are other deli commodities, tested commodities were chosen because of their consumer popularity.

Conclusion

With violet-405 nm fluorescence excitation, fluorescence responses for all commodities were greater than background at all measured wavelengths, 464-799 nm for both SS and HDPE. Although HDPE provides its own response, commodities were still detectable on both stainless steel and HDPE surfaces. The three wavelengths selected for detailed testing: 475, 520, and 675 nm, will allow detection of all cheeses and meats tested.

Phase II- Changes in Spectra with Brand and Time

Materials and Methods

Coupon Preparation

In contrast with the phase one study, only stainless steel coupons were used for testing.

Sample Preparation

Slices of three brands of each type of cheese (American, cheddar, provolone, and Swiss) and meat (chicken, ham, roast beef, and turkey) were acquired from at least two different grocery store deli departments. All commodities were sliced and uses on the first day as purchase. The end slices were discarded and the middle slice was used for experimentation. Three replicate samples were bored and placed in a line on a stainless

steel coupon. All three brands of a particular commodity were placed on the same SS

coupon (Figure 13). The cork borer was wiped free of debris and rinsed with water

between each brand.

Figure 13 American cheese samples (left) and turkey samples (right) organized by brand on stainless steel coupons.

Hyperspectral Data Acquisition

Coupons were repeatedly imaged over a period of 14 days, on days 0, 1, 2, 4, 8,

11, and 14.

Sample Storage

Samples remained on their coupons over the 14-day experimentation period.

Coupons were stored in sealed containers in a dark environment at ambient room

temperature. Meat and cheese coupons were stored in separate containers.

Image Analysis

Nine circular regions of interest (81 pixels), as described previously for Phase I,

were used to analyze punches on a single coupon. Brands were analyzed based on Day 0

results and over time. Cheese and meat graphs were scaled differently in terms of

intensity to better see characteristics of spectra. Within commodity type, the scale was kept constant.

Statistical Analysis

The PROC MIXED procedure (SAS, Version 9.2, Cary NC) was used for all statistical analyses. The dependent variable was the measured fluorescence intensity. Other variables were DAY of the measurement, BRAND, and PUNCH, which were the individual punched sample. Separate analyses were run for meat and for cheese products. The statement "Random PUNCH(BRAND)" was used to correct for repeated measures. BRAND and PUNCH were always treated as class variables. Separate analyses were run with DAY as a class variable and as a continuous variable.

Results

Hyperspectral Fluorescence Imaging of Cheese Brands

The fluorescence spectra of three brands of American, cheddar, provolone, and Swiss cheese on stainless steel coupons illuminated with violet-405 nm light for fluorescence excitation were collected. At all measured wavelengths between 464-799 nm, all tested commodities evidenced fluorescence responses with a greater intensity than the stainless steel background (Figure 14, Figure 15, Figure 16, Figure 17).

For American cheese (Figure 14), broad RFI peaks occurred at wavelengths between 520-550, 550-580, and 660-680 nm. In terms of peak ratios, the smaller the peak is at 520-550 and 550-580 nm, the higher the corresponding peak is at 660-680 nm.

Cheddar cheese (Figure 15), evidenced fluorescence response peaks between 520-550, 550-580, and 660-680 nm. Cheddar C brand has a higher fluorescence response,

especially between 464-650 nm, than Cheddar A or Cheddar B. Differences in peak intensity at 660-680 nm should also be noted for Cheddar A and B. Differences in fluorescence response were seen at 660-680 nm for Cheddar A and B, while their peaks at 520-550 and 550-580 nm were similar.

For provolone cheese (Figure 16), broad fluorescence responses occurred at wavelengths between 520-550, 550-580, and 660-680 nm. For Provolone A and Provolone B, a small peak also occurs at 624 nm. A distinct difference in peak amplitude can be seen at 660-680 nm; while Provolone A showed a strong fluorescence response at this wavelength, Provolone B showed a more moderate response and Provolone C showed very little response.

Swiss cheese evidenced fluorescence responses at 520-550, 550-580, 660-680, and also a distinct peak at 624 nm. A range of amplitude differences between brands can be seen in Figure 17.

Figure 14 Relative fluorescence intensity of different brands of American cheese at day 0 with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).

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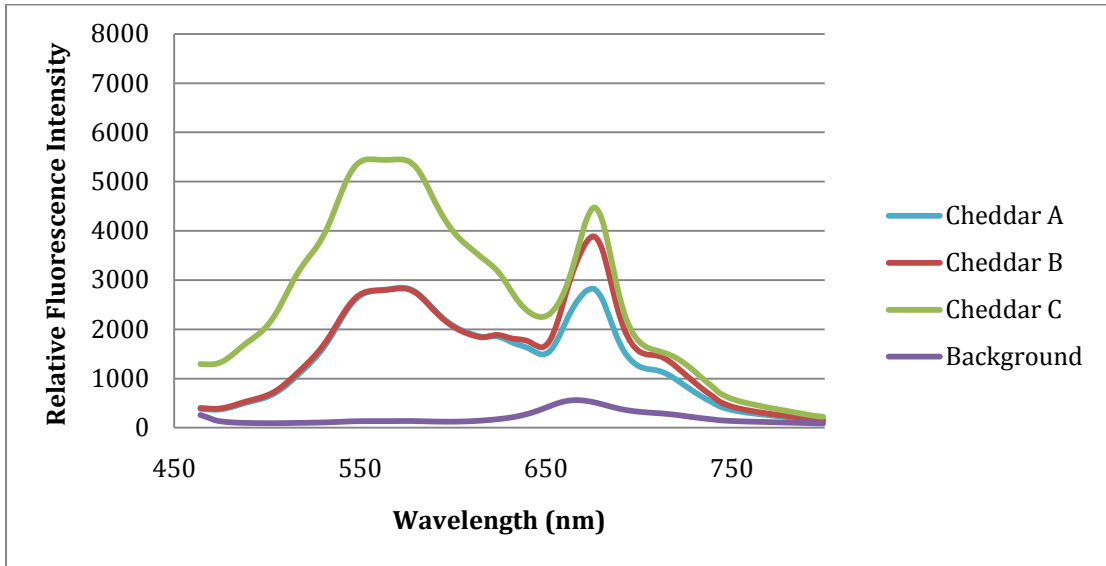
Figure 15 Relative fluorescence intensity of different brands of cheddar cheese at day 0 with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
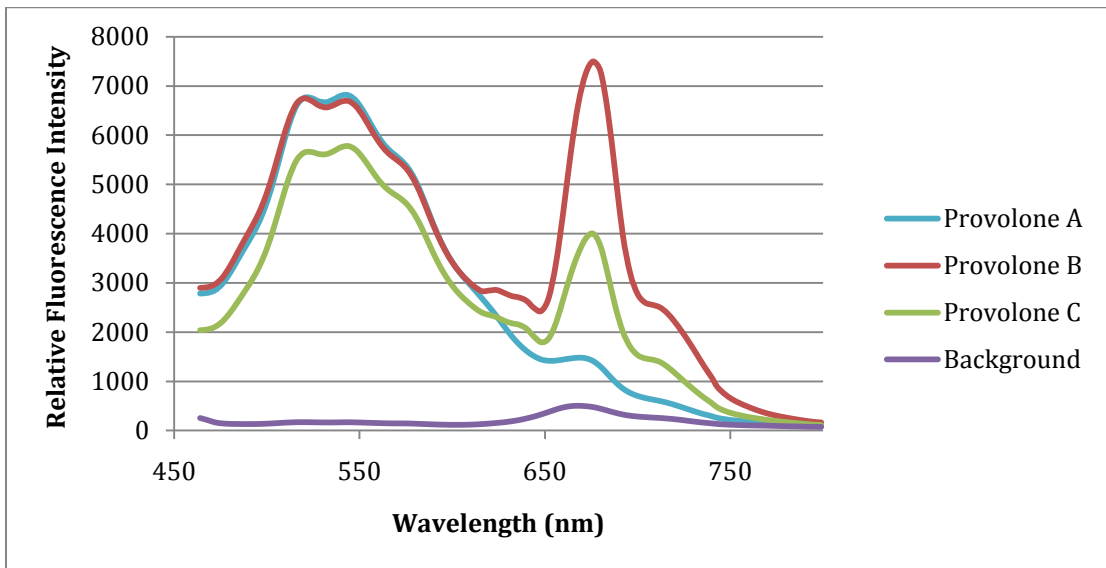
Figure 16 shows the different brands of provolone cheese at day 0 with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
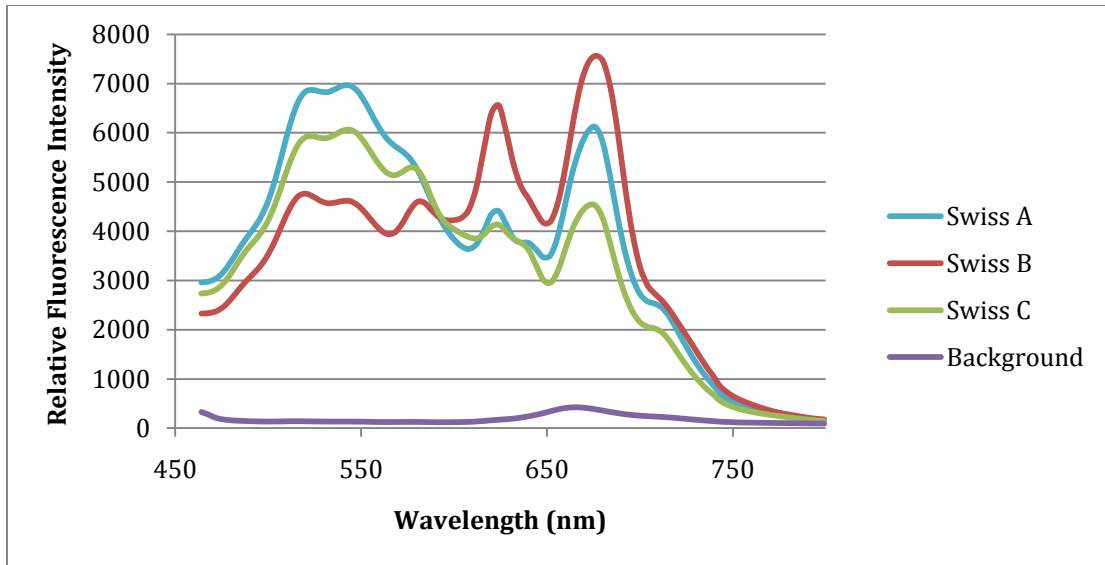
Figure 17 Relative fluorescence intensity of different brands of Swiss cheese at day 0 with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).

Hyperspectral Fluorescence Imaging of Meat Brands

The fluorescence response spectra of three brands of chicken, ham, roast beef, and turkey on stainless steel coupons excited with violet-405 nm light for fluorescence excitation was collected. At measured wavelengths between 464-640 nm, all tested commodities fluoresced with a greater intensity than the stainless steel background (Figure 18, Figure 19, Figure 20, Figure 21).

For all types of meats tested, the spectral pattern was the same regardless of brand, except for ham. For ham, a broad RFI peak occurred at 475-520 nm. One brand of ham, Ham C, showed an additional peak at 660-680 nm (Figure 18). All brands of chicken and turkey fluoresced with highest intensity between 475-520 nm. No spectral pattern variation was noted, but amplitude did vary between brands. Roast beef showed the weakest fluorescence response of all tested commodities and had fluorescence peaks

at 600 and 640-660 nm. No difference in spectral pattern was noted between brands, but

small changes in amplitude between brands were seen(Figure 21).

Figure 18 Relative fluorescence intensity of different brands of ham at day 0 with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
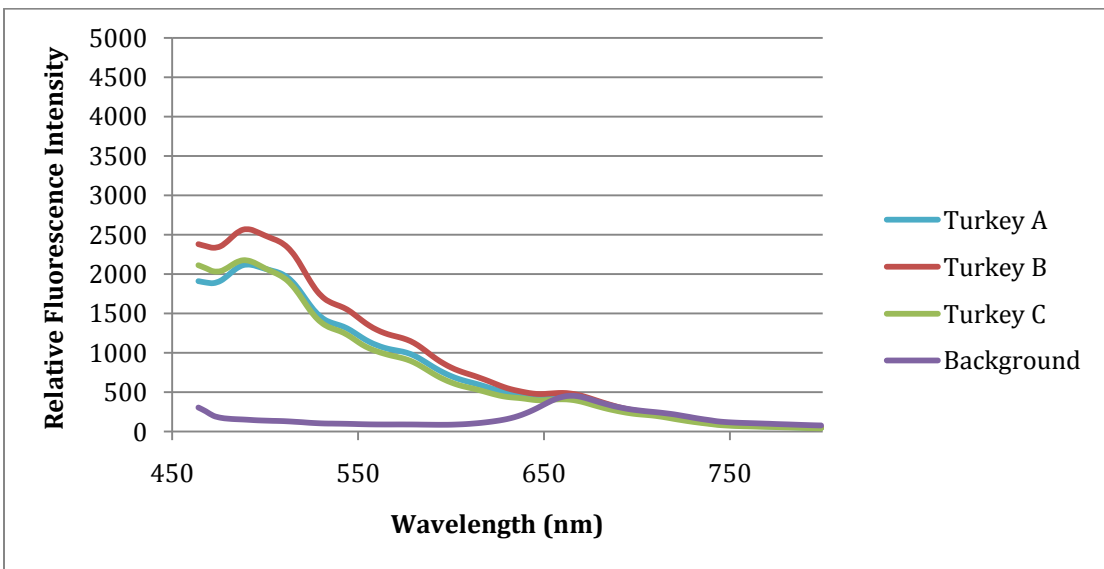
Figure 19 Relative fluorescence intensity of different brands of turkey at day 0 with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
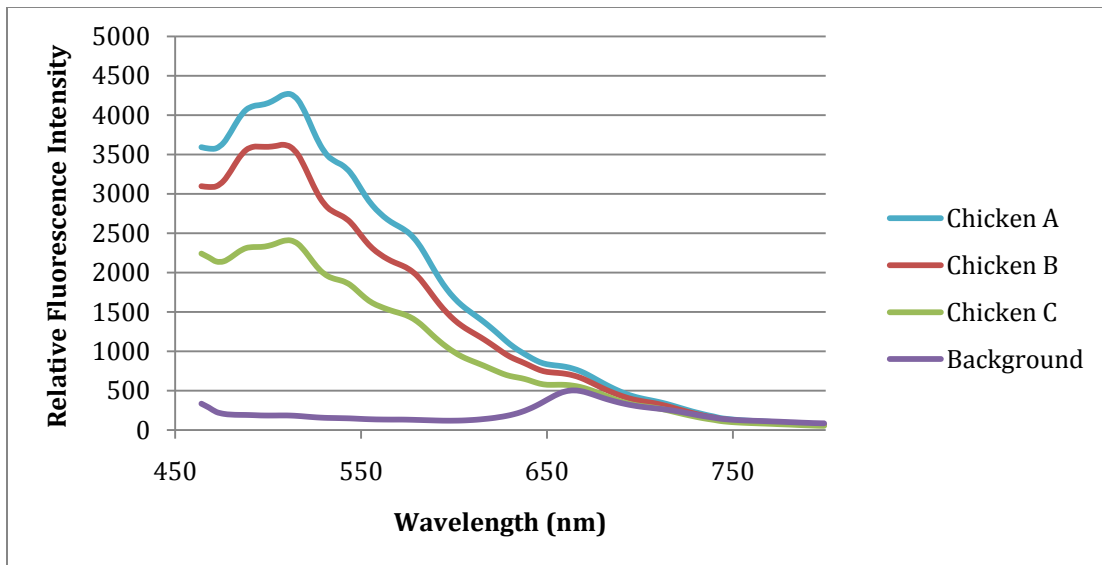
Figure 20 Relative fluorescence intensity of different brands of chicken at day 0 with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
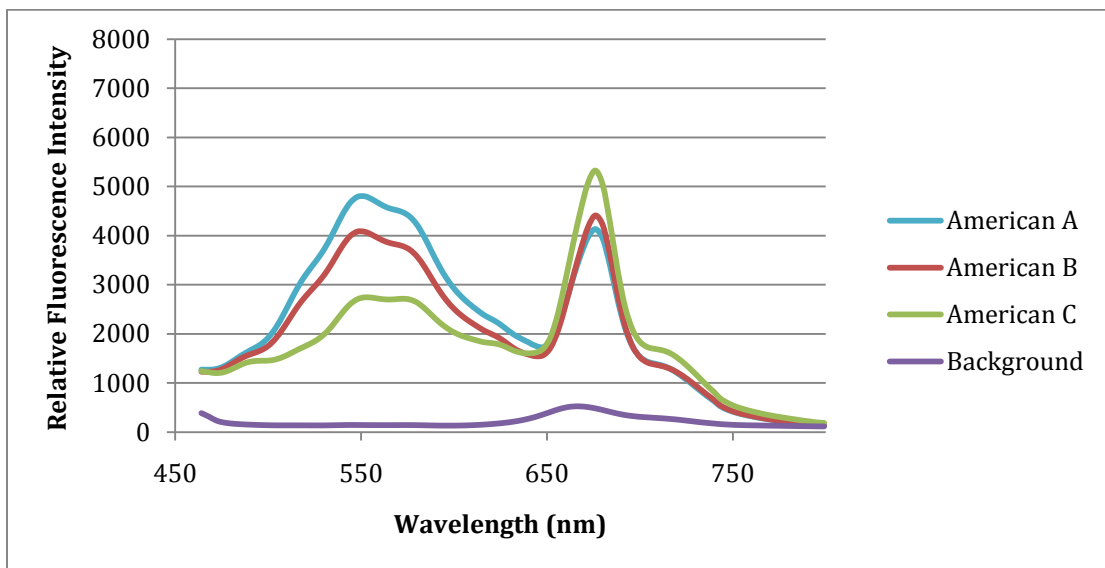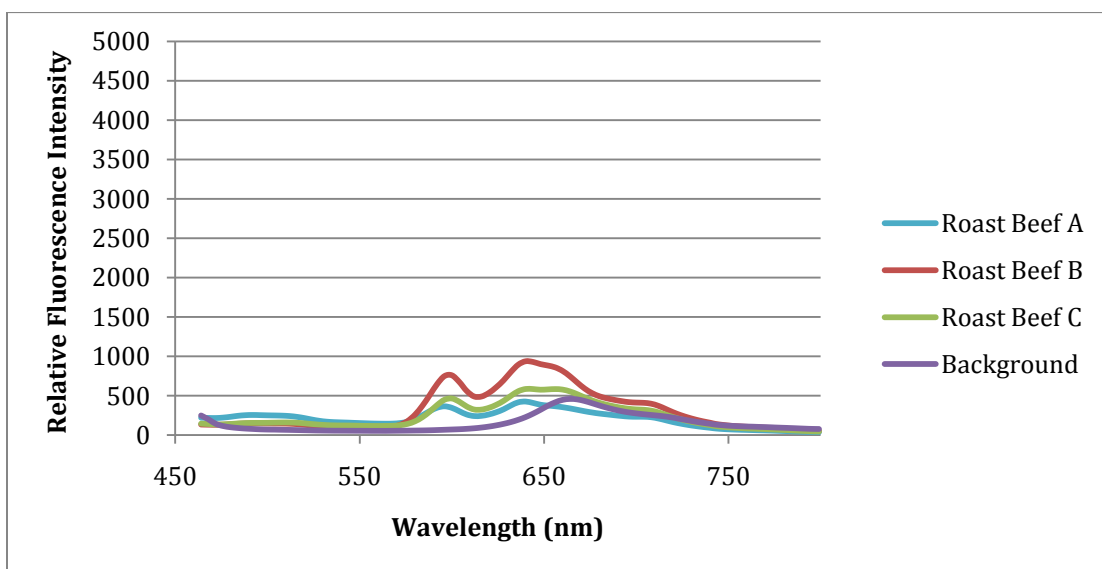

Figure 21 Relative fluorescence intensity of different brands of roast beef at day 0 with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).

## Spectral Changes over Time

Spectral data was collected when samples were imaged over a 14-day period on days 0, 1, 2, 4, 8, 11, and 14. At 520 nm, all tested commodities showed an overall

increase in fluorescence response over the 14-day period. Additionally, at 520 nm for all tested commodities, there was a significant difference in fluorescence response based on changes in day (p<0.001).

For all cheese commodities, there was an increase in amplitude for 520-550 and 550-580 nm peaks. Also, all cheeses saw a decrease in fluorescence intensity at 660-680 nm from the initial day 0 peak. Cheeses had the strongest fluorescence responses at 520-550, 550-580, and 660-680 nm (Figure 23, Figure 24, Figure 25, Figure 26). Swiss cheese had an additional peak at 624 nm (Figure 26).

For all meat commodities, there was an increase in amplitude for the broad major peak 480-520 nm peak (Figure 27, Figure 28, Figure 29, Figure 30). Roast beef produced additional peaks at 600 and 640-660 nm (Figure 29). It should be noted that cheeses had a much greater fluorescence response than meats.
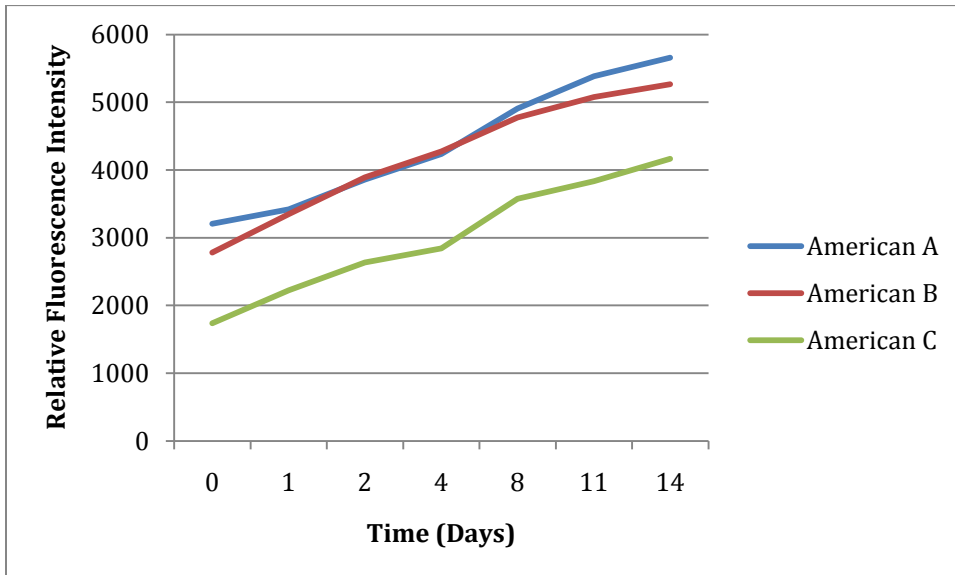
Figure 22 Relative fluorescence intensity over time for American cheese at 520 nm.
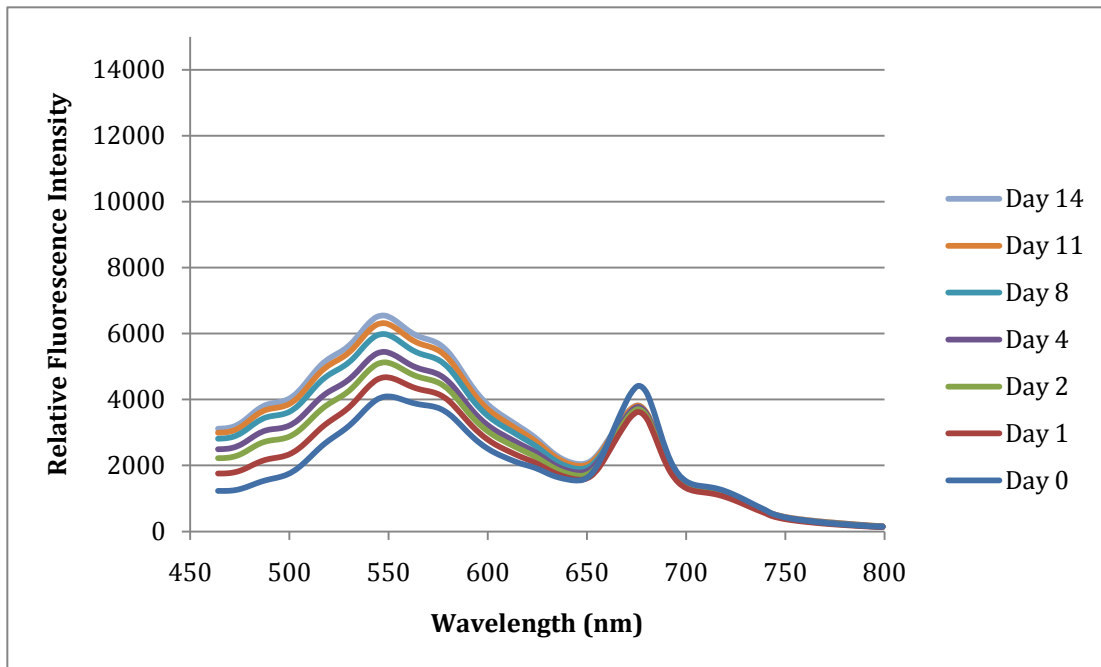
Figure 23 Relative fluorescence of brand American B American cheese over time with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
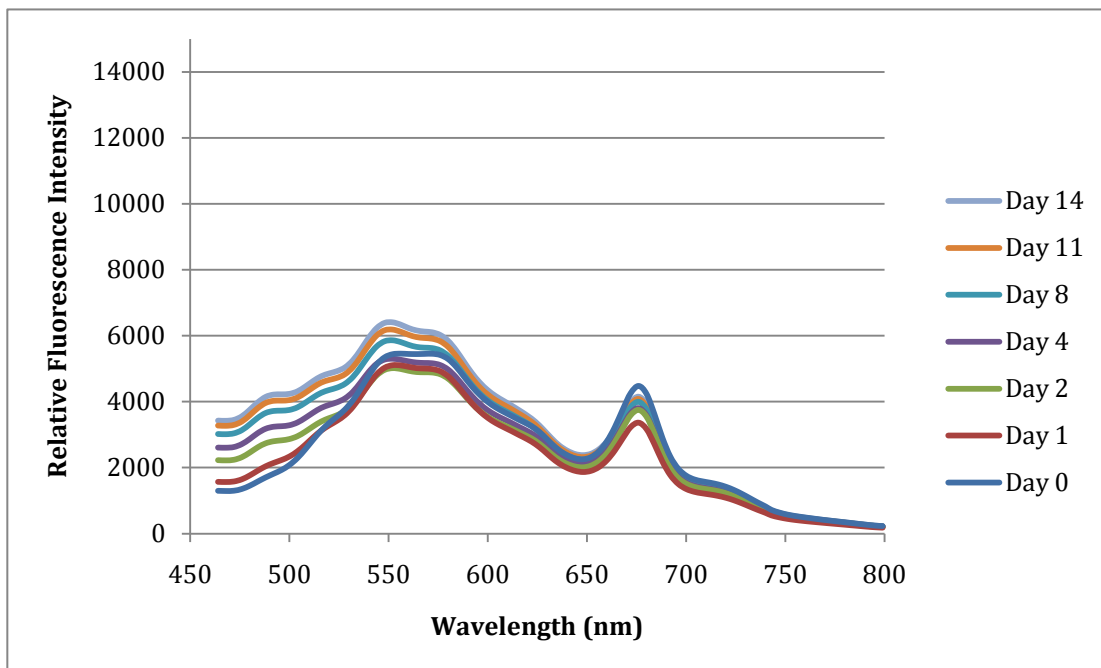
Figure 24 Relative fluorescence of brand Cheddar C cheddar cheese over time with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).

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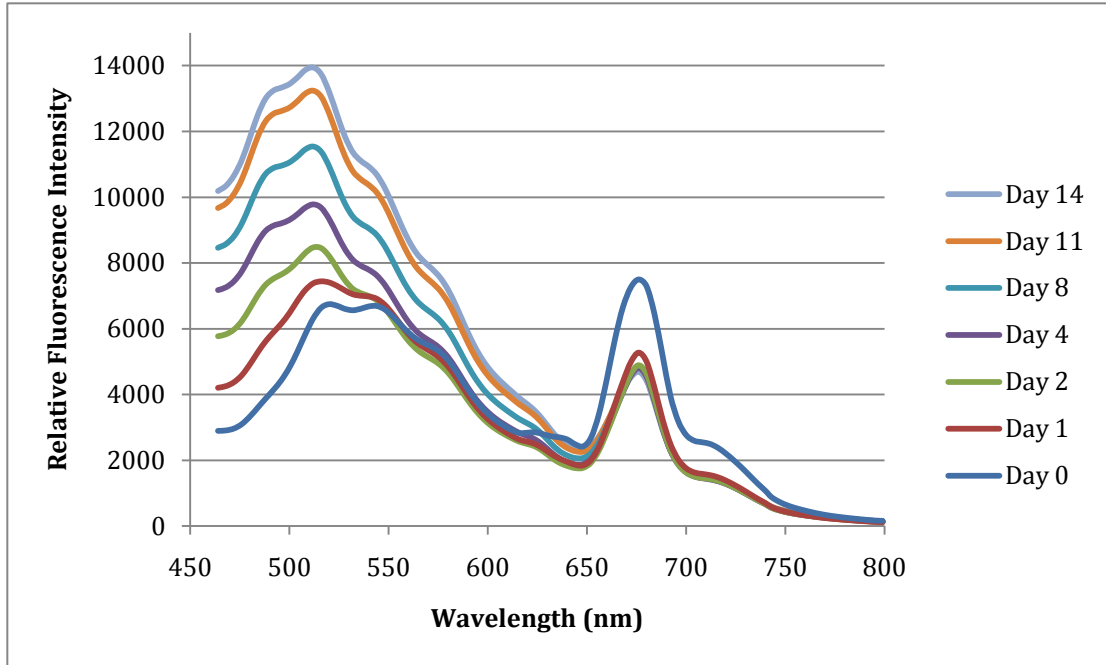
Figure 25 Relative fluorescence of brand Provolone B provolone cheese over time with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
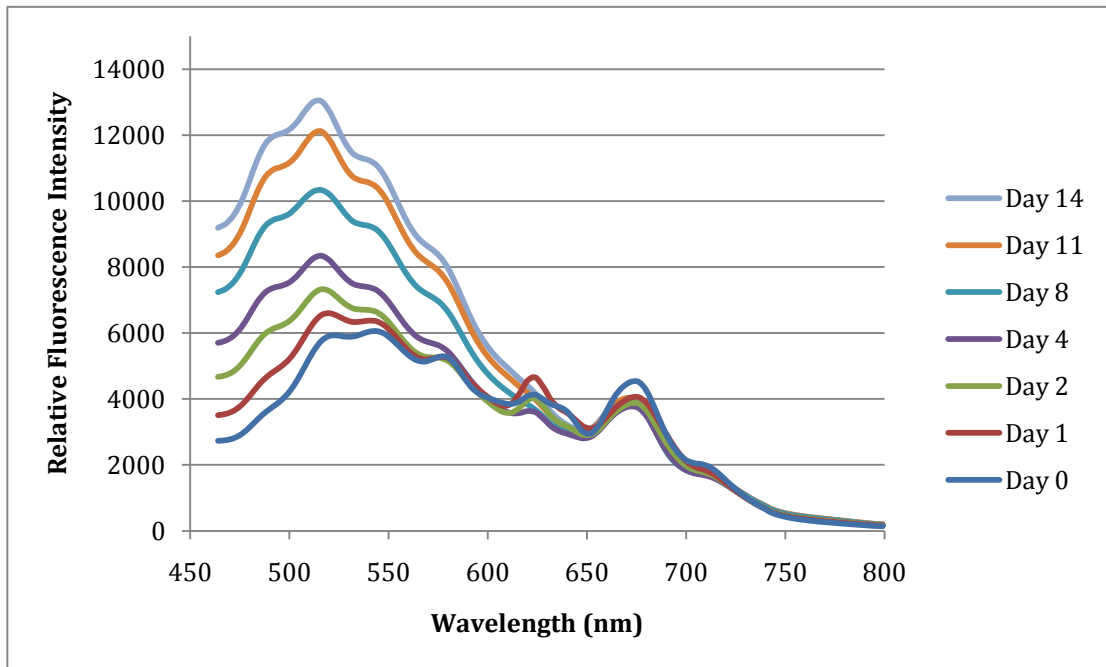
Figure 26 Relative fluorescence of brand Swiss C Swiss cheese over time with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
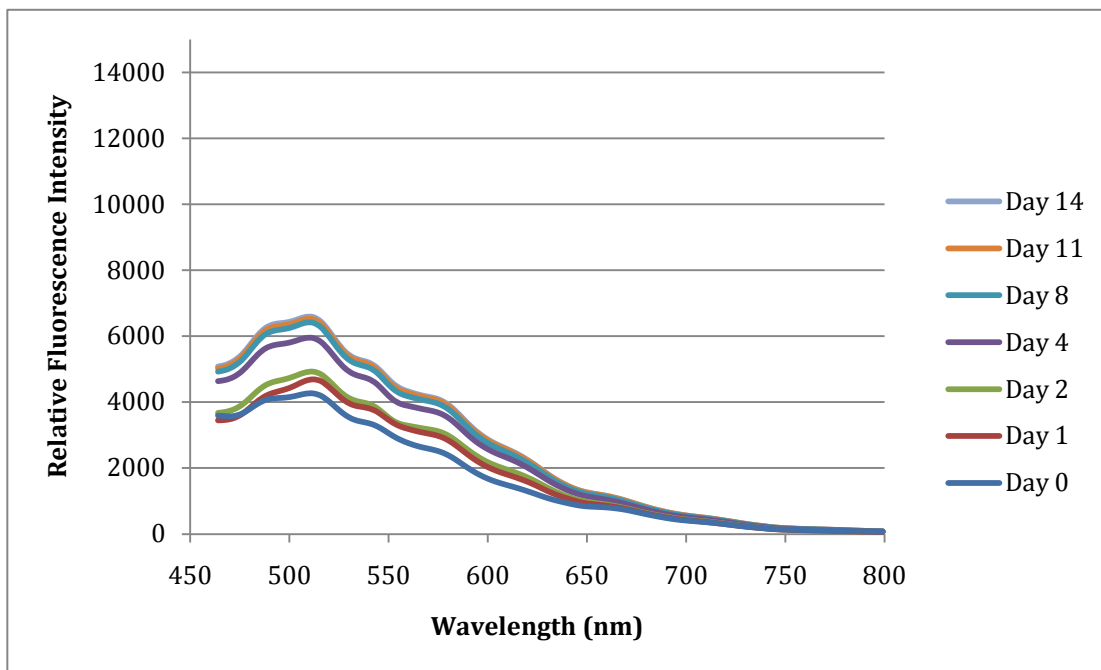
Figure 27 Relative fluorescence of brand Chicken A chicken over time with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
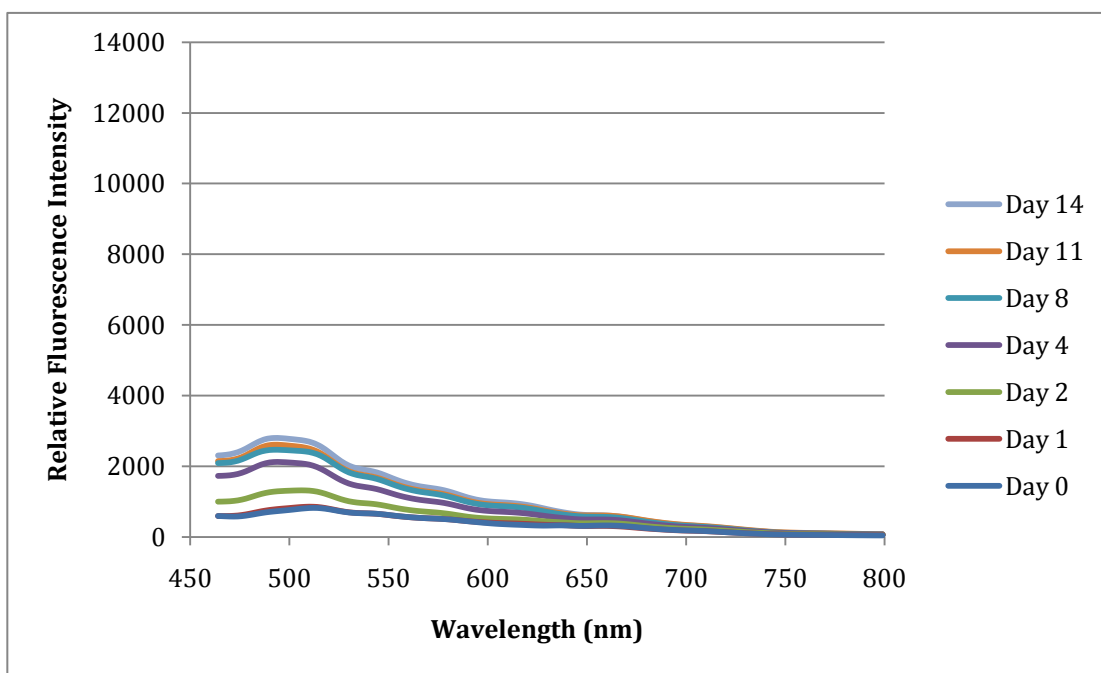
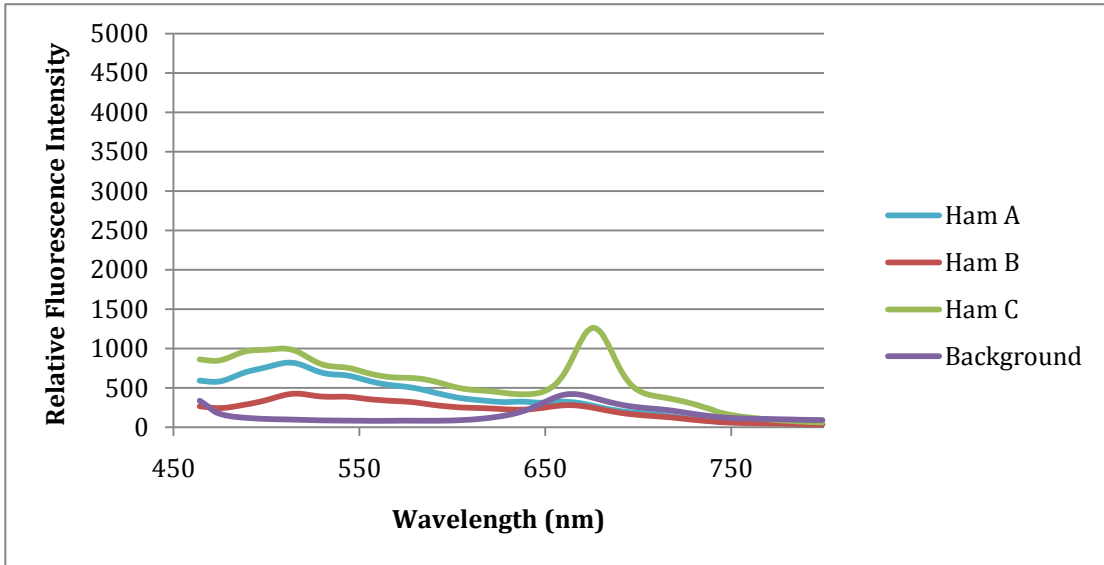**Figure 28 Relative fluorescence of brand Ham A ham over time with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).**
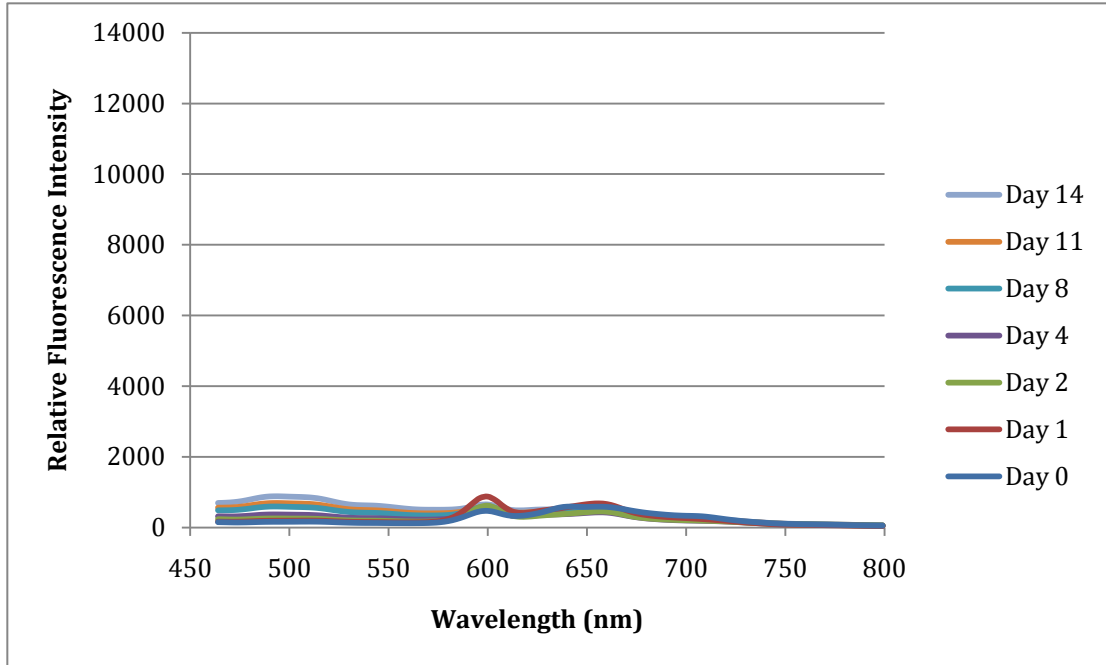
Figure 29 Relative fluorescence of brand Roast Beef C roast beef over time with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).
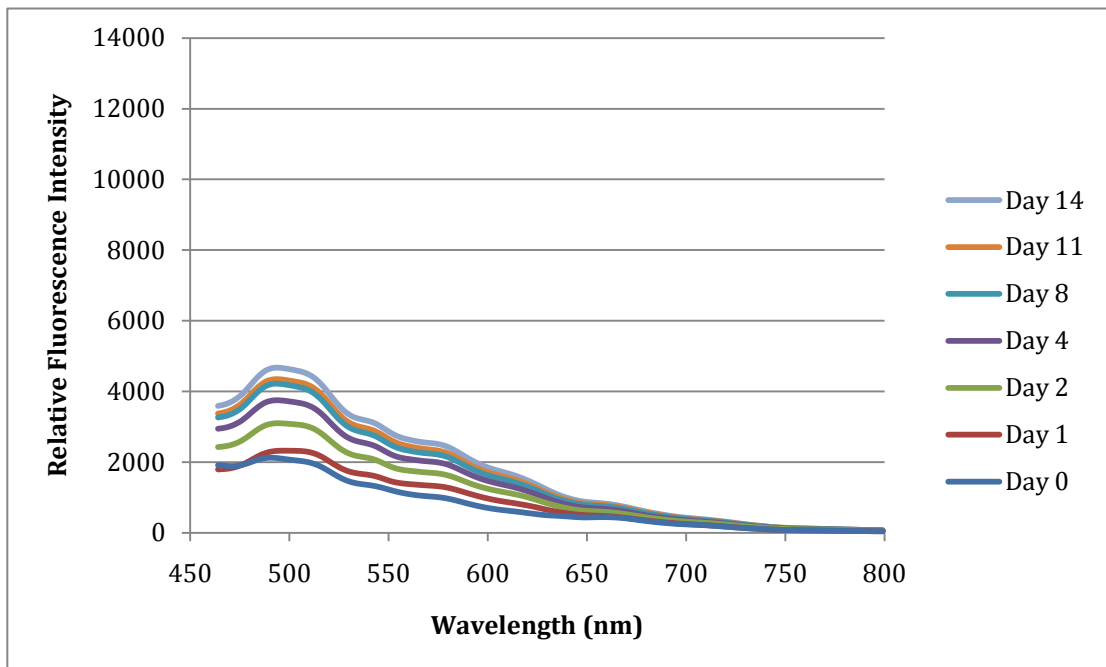
Figure 30 Relative fluorescence of brand Turkey A turkey over time with violet-405 nm light excitation between 464-799 nm on a stainless steel surface (n=3).

Discussion

Different brands of deli commodities impacted the amplitude of fluorescence response, but in general, did not affect the spectral pattern of the commodity type. Additionally, over time the overall fluorescence responses for all commodity types increased, making it easier to detect; no changes to the spectral patterns were noted. Results were consistent with the findings for Phase I, supporting the prior selection of 475, 520, and 675 nm as a minimum subset of wavelengths for detection of deli commodities.

A variety of deli commodity brands were tested to determine if brand had an effect on the spectral data collected. Only differences in peak amplitude were seen with American cheese brands (Figure 14). It is hypothesized that since American cheese is made from a mixture of cheeses or a mixture of dairy ingredients, this variation in peak amplitude could be due to the ratio of ingredients used to produce American cheese (21CFR1.133). At 520 nm, Cheddar C brand has a significantly different fluorescence response than Cheddar A or Cheddar B ($p<0.001$). It is hypothesized that this shift in amplitude is due to the age of the cheddars. Cheddar cheese is commonly sold at different ages, and age affects the composition of the cheese. As cheese ages, water evaporates, lowering the water activity, and the other compounds in the cheese are concentrated. With less interference from water, the compounds would be more available to provide a fluorescence response and would cause a higher response. Also, a difference in fluorescence response is seen at 660-680 nm for Cheddar A and B, while their peaks at 520-550 and 550-580 nm were similar. It is hypothesized that ingredient variability could cause this change in amplitude. For provolone cheese, differences in peak

amplitude at 660-680 nm were seen between all three brands. This difference is hypothesized to be variation in ingredient levels with compounds fluorescing at 660-680 nm. Swiss cheese showed unique spectral characteristics compared to the other cheese commodities tested (Figure 17). There were a range of amplitude differences between brands, which are hypothesized to be differences in age of the Swiss and level of propionic acid production. Age of cheese would concentrate compounds, while propionic acid production would cause degradation of certain compounds. Each type of cheese (American, cheddar, provolone, Swiss) produced a distinct spectral characterization; however, all major peaks fell within the ranges of 520-550, 550-580, and 660-680 nm. In addition, all varieties of Swiss cheese showed a distinct peak at 624 nm (Figure 17).

For all types of meats tested, the spectral pattern was the same regardless of brand, except for ham. Ham C showed an additional peak at 660-680 nm (Figure 18). It is hypothesized that this peak may represent chlorophyll in the ham. This is a peak commonly seen in cheese products because chlorophyll from the grass cows eat is passed into their milk and therefore, naturally present in cheese (Bendall 2001, Wold 2005). This peak is not commonly found in meats. One explanation for the appearance of this peak is that ham, being a type of cured meat, maintains its distinct pink color from the addition of nitrites. While a common nitrite additive is sodium nitrite, a consumer trend toward "nitrate-free" cured products is growing in popularity. To be able to remove added nitrites from the food label and call a product a "no-nitrite-added cured meat", more creative techniques are taken to add nitrites. One way to do this is by the addition of celery juice/powder, which naturally contains nitrate; nitrate can be converted to nitrite

in the meat product with a nitrate reducing culture (Sebranek 2007). Since celery also naturally contains chlorophyll, the addition of a celery additive would likely produce a peak at 660-680 nm.

At 475 and 520 nm, all tested cheese commodities showed an overall increase in fluorescence over the 14-day period. The main reason for the increase in fluorescence for cheese commodities is the amplitude increase of broad 520-550 and 550-580 nm peaks. Over time, water evaporated from the samples and concentrated the compounds. With less interference from water, the compounds were more available to fluoresce. Also, over time, oil migrated to the surface of the samples; oils could add to the fluorescence increase at these peaks. Not all fluorescence peaks for cheeses increased over time. In fact, all cheeses saw a decrease in fluorescence intensity at 660-680 nm from the initial day 0 peak. It is hypothesized that degradation of compounds that fluoresce in this range is the main reason for the decrease in fluorescence intensity.

At 475 and 520 nm, all tested meat commodities showed an overall increase in fluorescence over the 14-day period. The main reason for the increase in fluorescence for meat commodities is the amplitude increase of the broad 470-520 nm peak. Water evaporation from the samples and compound concentration made the compounds more available for fluorescence. While changes in amplitude were observed over time for all commodities, no changes in spectral characterization were seen. Cheeses still had the strongest fluorescence responses between 520-550, 550-580, and 660-680 nm. Swiss cheese had an additional peak at 624 nm. A broad major meat peak occurred between 480-520 nm. Roast beef produced additional peaks at 600 and 640-660 nm.

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One limitation to this study is that only three brands of a commodity were studied. Many more brands of commodities exist; however, if there was a wide variation in spectral pattern among brands, it would have likely been noted within the brands tested.

Conclusion

All brands tested for a specific commodity had similar spectral characterization, except for the Ham C brand, which showed an additional peak between 660-680 nm. No adjustment to the minimum subset of selected wavelengths is needed due to brand variation. All commodities imaged over time produced the same spectral characterization from Day 0 to Day 14. No adjustment to the minimum subset of selected wavelengths 475, 520, and 675 nm is needed due to age of residue on surface. The portable device should be tuned to cycle through the selected wavebands: 475, 520, and 675 nm. No additional wavebands need to be added at this time.

Summary

It is feasible to detect deli commodities using hyperspectral imaging with a subset of wavelengths, which can potentially allow for the detection of deli residues on food contact surfaces in a deli environment. This research was done keeping in mind the constraints of a portable hyperspectral imaging system and a deli environment, therefore, it is reasonable to further this research by using the portable hyperspectral imaging system for deli slicer contamination detection.

With the use of hyperspectral imaging, all tested deli commodities evidenced fluorescence responses under LED 405 nm light excitation between 464-799 nm.

Commodities also evidenced fluorescence with greater intensity than common deli

surfaces HDPE and stainless steel. Each commodity produced a unique, repeatable

spectral pattern that varied in amplitude based on variation in brand and time. All cheese

types produced overlapping peaks and all meat types produced overlapping peaks,

allowing for a subset of wavelengths for rapid detection to be selected. Based on ambient

lighting interference and peak intensities for meat and cheese commodities, 3

wavelengths 475, 520, and 675 nm were needed to adequately detect all tested

commodities.

Chapter 5: Portable Imaging Device

Introduction

This chapter examines the use of a portable imaging device for real-time deli department cleaning and sanitation verification. Single and dual-commodity deli residue detection was tested. The device was programmed to automatically cycle through the three selected wavelengths: 475, 520, and 675 nm. When a potential contaminant was detected at one of these wavelengths, hyperspectral images were acquired of the suspect area. Successful detection of potential contaminants in this deli setting would establish a real-life application of the portable imaging device in a deli environment and determine if imaging technology could be used in a way that would enhance current cleaning and sanitation verification methods.

Phase III- Deli slicer contamination detection

Materials and Methods

Deli Slicer Initial Preparation

An in-house commercial deli slicer (General Slicing/Red Goat Disposers Model # GS300, TN) was used for all sample slicing. Prior to the start of experiments, the slicer blade was inspected for rust and blade sharpness. Rust was removed with an all-purpose rust remover (Barkeeper's Friend, Indianapolis IN) and the blade was sharpened with a whetting stone. All surfaces of the slicer were washed with warm water and soap to

remove surface debris and then wiped dry. Food grade sanitizer was applied liberally, and then the surface of the slicer was scrubbed with a sponge and small brush, according to the manufacturer's instructions, and allowed to air dry.

Figure 31 Commercial deli slicer used for testing.

Sample/Surface Preparation

Blocks of deli meats and cheeses (same brands used in previous experiments) were purchased from a local grocery deli. For single-commodity preparation, a deli block was placed on the deli slicer and sliced according to the deli slicer manufacturer's instructions. Five slices were produced and then the slicer was turned off and unplugged for safety. The deli block and subsequent slices were removed from the slicer surface and slices were discarded, as the aim of this experiment was to detect deli residues left on the slicer.

For dual-commodity preparation, one cheese and one meat block was sliced sequentially without cleaning or sanitizing in between. The cheese commodity was sliced for five slices and then the meat commodity was sliced for five slices. The slicer

was then turned off and unplugged for safety and the deli block and subsequent slices were removed from the surface. Dual-commodity combinations include: American cheese and turkey, Swiss cheese and ham, cheddar cheese and roast beef, and provolone cheese and chicken. These combinations were created to simulate residual build-up from multiple types of commodities being sliced on the same slicer.

Image Acquisition

A portable imaging device (Lefcourt et al. 2013) with LED fluorescence excitation was used to survey the deli slicer for deli residuals. With the overhead lights off, the portable imaging device with LED illumination was set to automatically cycle through the wavelengths 475, 520, and 675 nm. When a location of interest was detected, the device was immobilized on a tripod and hyperspectral images, between wavelengths 465-720 nm with 57 bands and 5 nm intervals, were acquired. This scanning and imaging process was repeated until the entire surface of the slicer had been scanned. Images of a commercial deli slicer were acquired before slicing commodities, after slicing commodities, after cleaning the slicer, and after sanitizing the slicer.

Surface Cleaning/Sanitation

Soap and a food grade sanitizer (Simple green d, Sunshine Makers Inc., Huntington Beach, CA) were used for cleaning and sanitizing purposes, respectably. To clean the deli slicer, the surfaces were washed with a sponge soaked in warm water and soap to remove surface debris. The surfaces were then wiped dry with a disposable towel. To sanitize the deli slicer, food grade sanitizer was liberally applied to all slicer surfaces; the surfaces were then wiped down with a sponge and allowed to air dry. The portable imaging device was used to survey the slicer surfaces post-sanitation to verify

the cleaning and sanitation procedures were adequate to remove deli commodity residues from the slicer. If locations of interest were found post sanitation, more intensive sanitation procedures were required; a small brush with sanitizer was used to scrub the affected area. The deli slicer was imaged repeatedly, until no locations of interest were detected on the slicer.

Image Analysis

The acquired hyperspectral data was used to create images at selected wavelengths. Images were created between 470-720 nm at 5 nm intervals; the emphasis of image analysis was focused on 475, 520, and 675 nm images. The system automatically adjusted the gain of the images displayed in the results section because images displayed are in 8-bit format, while images were acquired as 12-bit images. The adjustment to 8-bit was made for easier formatting.

Results

Single-Commodity Residue on Slicer Surfaces

Pre cleaning and sanitation, cheese residues on the deli slicer were detected when the portable imaging device was sweeping and cycling through 475, 520, and 675 nm. Cheese residues evidenced greater fluorescence responses at 520 and 675 nm than at 475 nm (Figure 32). American cheese residues were detected on the slicer blade and the spokes (Figure 32) that hold the deli commodity block. Cheddar cheese residues were detected on the front blade/slicing junction, the spokes, and the front left portion of the slicer. Provolone cheese residues were detected on the front blade/slicing junction and the front left portion of the blade. Swiss cheese residues were detected on the front

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blade/slicing junction and the exposed portion of the blade. After cleaning the deli slicer, fewer residues were detected on the surface. Post sanitation procedures, some residues were still detected.

Pre cleaning and sanitation, meat residues on the deli slicer were detected when the portable imaging device was sweeping and cycling through 475, 520, and 675 nm. Meat residues evidenced greater fluorescence responses at 475 and 520 nm than at 675 nm (Figure 32). The residues were confirmed to be on the surface when hyperspectral images were acquired. Turkey residues were detected on the front blade/slicing junction, the spokes (Figure 32), and the back blade junction. Chicken residues were detected on the front blade/slicing junction, the spokes, and the back blade junction. Ham residues were detected on the front blade/slicing junction and the back blade junction. Roast beef residues were detected on the front blade/slicing junction and the back blade junction. After cleaning the deli slicer, fewer residues were detected on the surface. Post sanitation procedures, even fewer residues were detected (Figure 33).

Figure 32 American cheese residue (left) and turkey residue (right) on spokes of deli slicer imaged with a digital camera (top) and portable imaging device with LED fluorescence excitation (bottom).
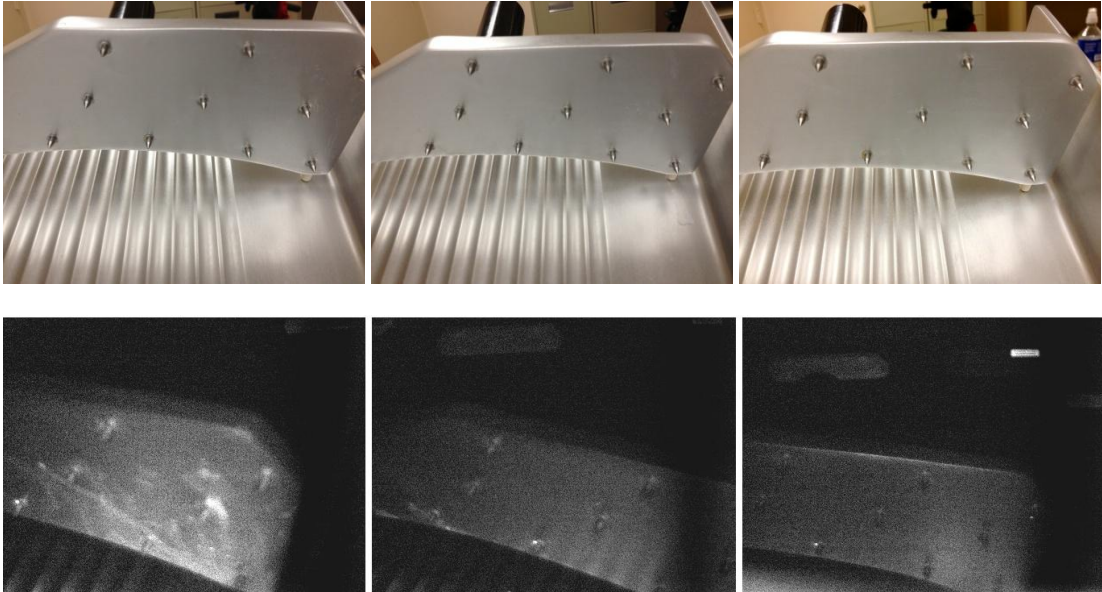
Figure 33 Turkey pre-cleaning/sanitation (left), post cleaning (middle), and post sanitation (right) at 475 nm, imaged with a digital camera (top) and a portable imaging device with LED fluorescence excitation (bottom).

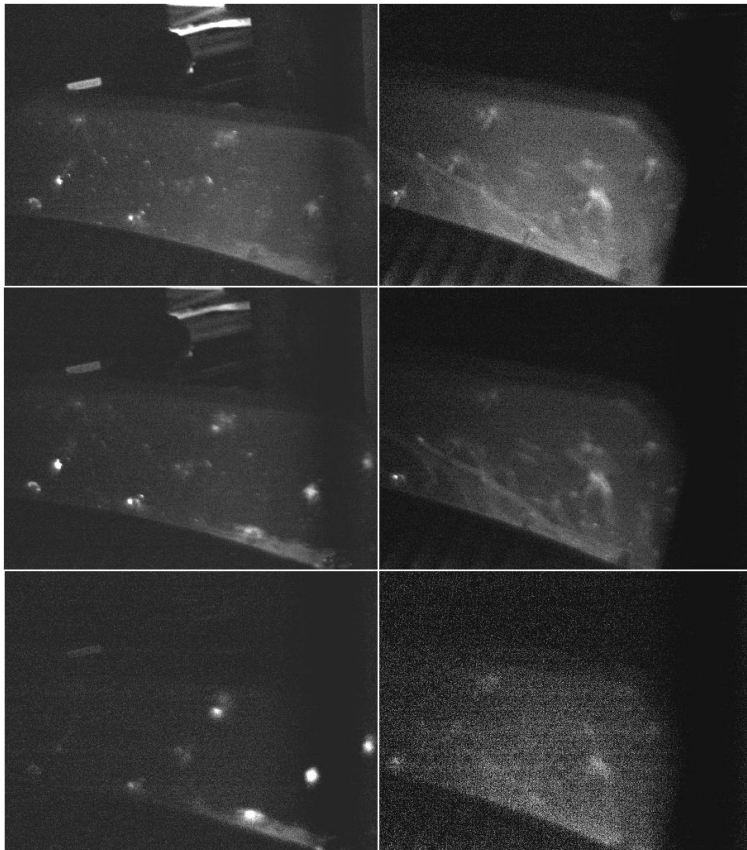## Dual-Commodity Residue on Slicer Surfaces

Pre cleaning and sanitation, dual-commodity residues on the deli slicer were detected when the portable imaging device was sweeping and cycling through 475, 520, and 675 nm. Dual-commodity residues showed a strong fluorescence response at all three wavelengths. Different portions of dual-commodity residues showed stronger fluorescence responses at 475 nm or at 675 nm; the fluorescence response was not uniform for a location of interest.

Roast beef and cheddar cheese residues were detected on the front blade/slicing junction and the back blade junction. Turkey and American cheese residues were detected on the front blade/slicing junction (Figure 34). Chicken and provolone cheese residues were detected on the front blade/slicing junction and the back blade junction. Ham and Swiss cheese residues were detected on the front blade/slicing junction.

Larger amounts of residue appeared to be present at locations of interest with dual commodity slicing in comparison to residue present at locations of interest with single commodity slicing. However, the additional residue did not affect effectiveness of cleaning and sanitation.

475 nm

520 nm

675 nm
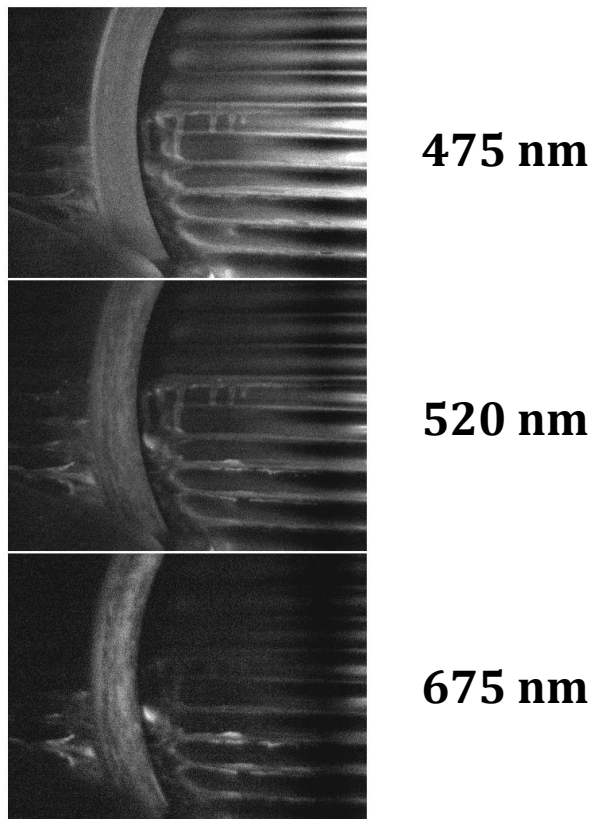
Figure 34 American cheese and turkey residue on slicer blade junction imaged with a portable imaging device with LED fluorescence excitation.

Problem Areas on Deli Slicers

Slicer surfaces with repeated contamination for cheese residues were found to be spokes that hold the deli block, the front blade/slicing junction, and the front left surface where the commodities slide pre and post slicing. Slicer surfaces with repeated

contamination for meat residues were found to be the spokes, the front blade/slicing junction, and the back blade junction. Overall, four main slicer surfaces with problem areas were identified (Figure 35).
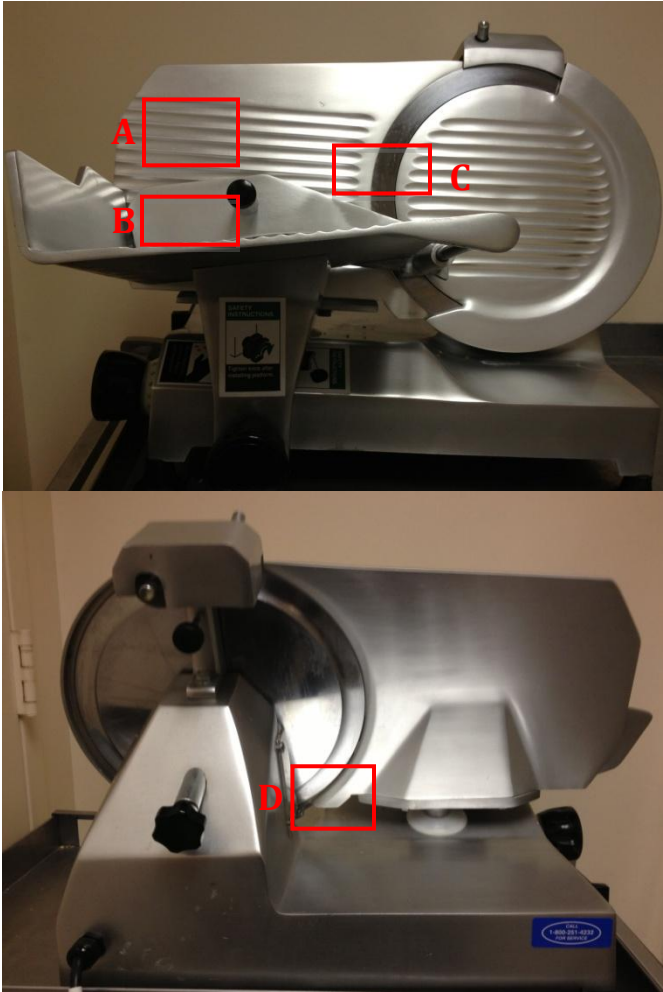
Figure 35 Problem areas: front surface where the commodities slide pre and post slicing (A), spokes that hold the deli block (B), blade/slicing junction (C), and bottom of the blade junction on the back side of the slicer (D).

Discussion

Deli commodity residues could be detected with the portable imaging device using the three prior selected wavelengths: 475, 520, and 675 nm. In general, cheese residues were easiest to detect with 520 and 675 nm, while meats were easiest to detect at

475 and 520 nm, reiterating that just one wavelength is not sufficient to adequately detect deli residues. Problem areas on the deli slicer where special attention should be paid when cleaning and sanitizing were identified.

With dual-commodity slicing, differences in residual responses are hypothesized to primarily be due to the fluorescence response of cheese versus meat. The larger amount of residue for a location of interest with dual-commodity residue vs. single-commodity residue could be attributed to the fact that more commodities were sliced.

The deli slicer needed to be fully cleaned and sanitized between trials, as not to influence the following trial's results. For all commodities sliced, the use of the portable imaging device was needed to sufficiently clean and sanitize the deli slicer. The device was used post sanitation to detect locations of interest and then the locations were immediately re-cleaned and re-sanitized. The locations were then viewed again with the imaging device, cycling through the wavelength subset, to determine if the residue had been removed from the area.

Areas that commonly remained contaminated following all cleaning and sanitation procedures included: the spokes that hold the deli block, the blade/slicing junction, the front surface where the commodities slide pre and post slicing, and the bottom of the blade junction on the back side of the slicer. Some of these points were exposed the longest to the deli commodities as they were being sliced, compared to other areas on the slicer. Other points were smaller spaces were debris could easily be trapped; and some areas are hard to clean and sanitize. It is hypothesized that these reasons are why these four specific points on the slicer were repeatedly contaminated.

One limitation to this experiment is that the experiment was done in a dark setting. Realistically, the portable hyperspectral imaging system will be implemented in a low, ambient light setting. Environmental light will be more of a factor and cause potentially more interference than a dark environment. In future experimentation in deli departments, a low, ambient light setting will be used when collecting data. Another limitation is that only the deli slicer was examined in this experiment. Deli departments have more than just a deli slicer that need inspecting; however, the reason the deli slicer was chosen for this experiment was because it is a known source of cross-contamination within the department.

Conclusion

The portable imaging device was able to detect residue on the slicer surface from all tested deli commodities. Using 475, 520, and 675 nm wavelengths, residues were still commonly detectable post cleaning and sanitation. The adequate removal of residue from the slicer required the use of the portable imaging device post sanitation to sweep the slicer surface to locate residual points of contamination where immediate cleaning intervention was taken. From testing numerous commodities, four areas on the slicer showed repeated contamination: the spokes that hold the deli block, the blade/slicing junction, the front surface where the commodities slide pre and post slicing, and the bottom of the blade junction on the back side of the slicer. Particular attention is needed when cleaning and sanitizing the slicer. It is suggested that changes in current cleaning and sanitizing procedures should be made that does not increase the amount of time needed for cleaning but instead redirects and puts emphasis on where time is spent. These areas can be determined by the portable hyperspectral imaging device.

Chapter 6: Conclusion and Future Recommendation

It is feasible to use a portable hyperspectral imaging device to enhance cleaning and sanitation procedures in deli departments. Deli commodity residues were detected at every stage of the deli slicer cleaning/sanitation process and the imaging device was used to pinpoint areas that needed additional cleaning. This imaging device proved to be a necessary element to proper cleaning and sanitation of the deli slicer surface. Where surfaces appeared to the eye as free of debris, residue was detected when the imaging device was used.

Inspection services or quality assurance/control departments could utilize this device as a tool to enhance cleaning and sanitation verification; the device could also be used as a tool to adapt current cleaning and sanitation procedures to focus on problem areas. Another use for the device could be the evaluation of the effectiveness of soaps and sanitizers, to determine which type of cleaner/sanitizer works best at removing residue. Further studies should be done to implement the use of this portable hyperspectral imaging device in an actual deli department.

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