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<https://youtu.be/DWLg50p9KyY>

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IMPROVE LIFE.



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The Next Generation of Food and Surface Disinfection: Harnessing Nature's Hydroxyl-Radical Process to Enhance Public Health

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Funding Agencies

Mitacs



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OF CANADA
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Agriculture and
Agri-Food Canada



Ontario
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Innovation
Alliance

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cleanworks



Health
Canada

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- **Disclosure:** *I do not have anything to disclose*

Learning Objectives

- Describe the science behind the hydroxyl-radical process.
- Recognize the activity of hydroxyl-radicals to inactivate viruses, bacteria, yeast, moulds and endospores.
- Describe different applications of the hydroxyl-radical process for food and health care sectors.

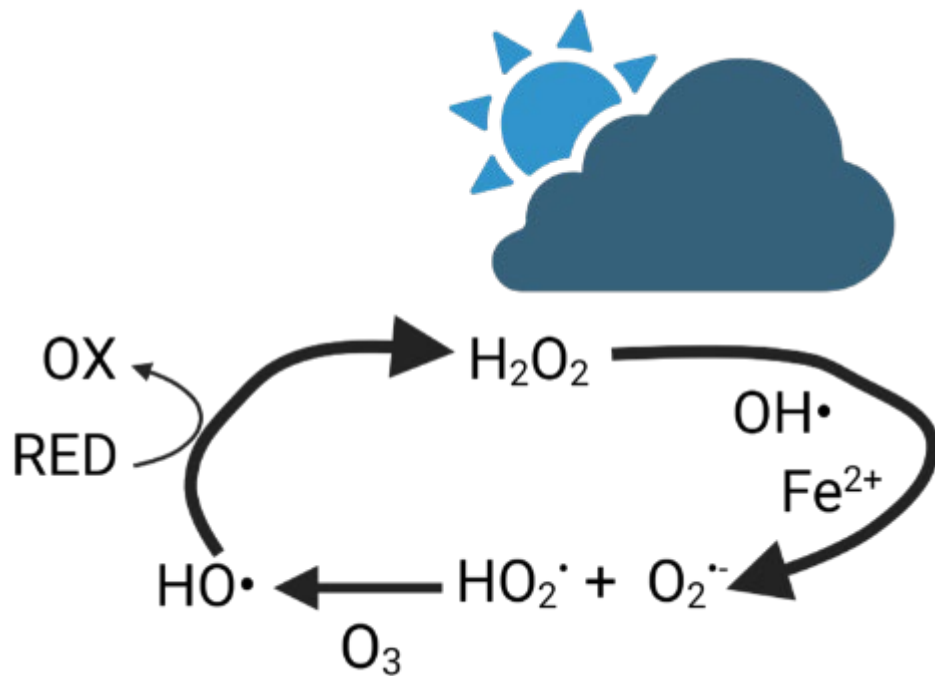
Outline

- The science behind the hydroxyl-radical process
- Origins of applying hydroxyl-radical process for food applications
- Overcoming the research to commercial application barrier
- Hydroxyl-radical process in the pandemic
- Food disinfection applications
- Future directions

A man in a white lab coat and safety glasses is leaning over a biosafety cabinet. The cabinet's front panel is open, revealing a blue work surface. On the surface, there is a piece of aluminum foil containing shredded green lettuce and a pink egg carton filled with brown eggs. The background shows a laboratory setting with shelves and equipment.

The Science

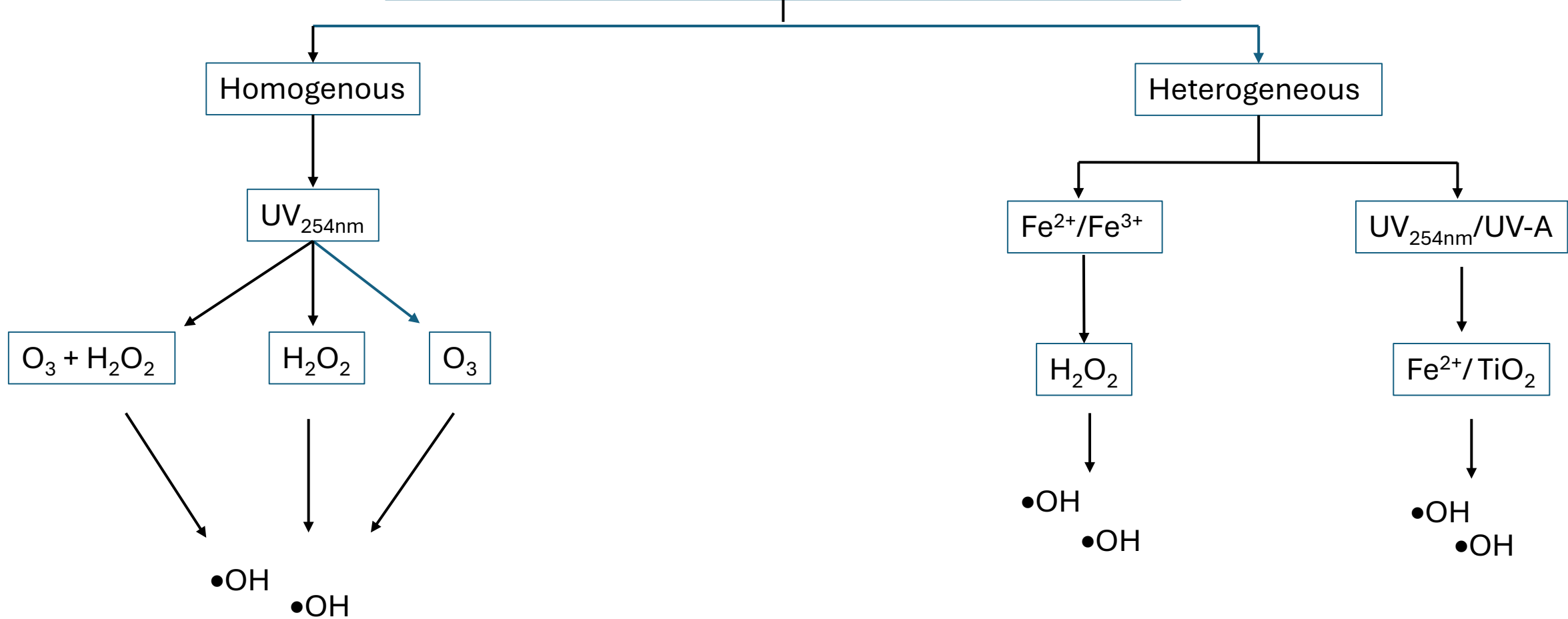
Hydroxyl-radicals



Oxidant	Oxidation Potential (V)
Fluorine [F ₂]	3.0
Hydroxyl radical [HO•]	2.8
Sulfate radical [SO ₄ ^{•-}]	2.5–3.1
Ozone [O ₃]	2.1
Persulfate [S ₂ O ₈ ²⁻]	2.1
Peroxymonosulfate [HSO ₅ ⁻]	1.8
Hydrogen peroxide [H ₂ O ₂]	1.8
Permanganate [MnO ₄ ⁻]	1.7
Chlorine dioxide [ClO ₂]	1.5



Hydroxyl-Radical Process /Advanced Oxidation Process

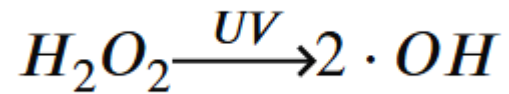


No residues or byproducts

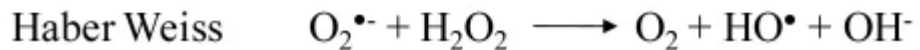
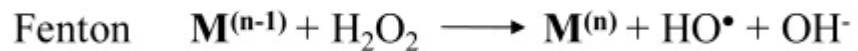
High hydroxyl-radical yield
Need to recover/recycle catalyst

The Chemistry

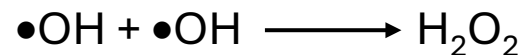
- Quantum Yield (efficiency of conversion per photon)
- Haber Weiss Reaction



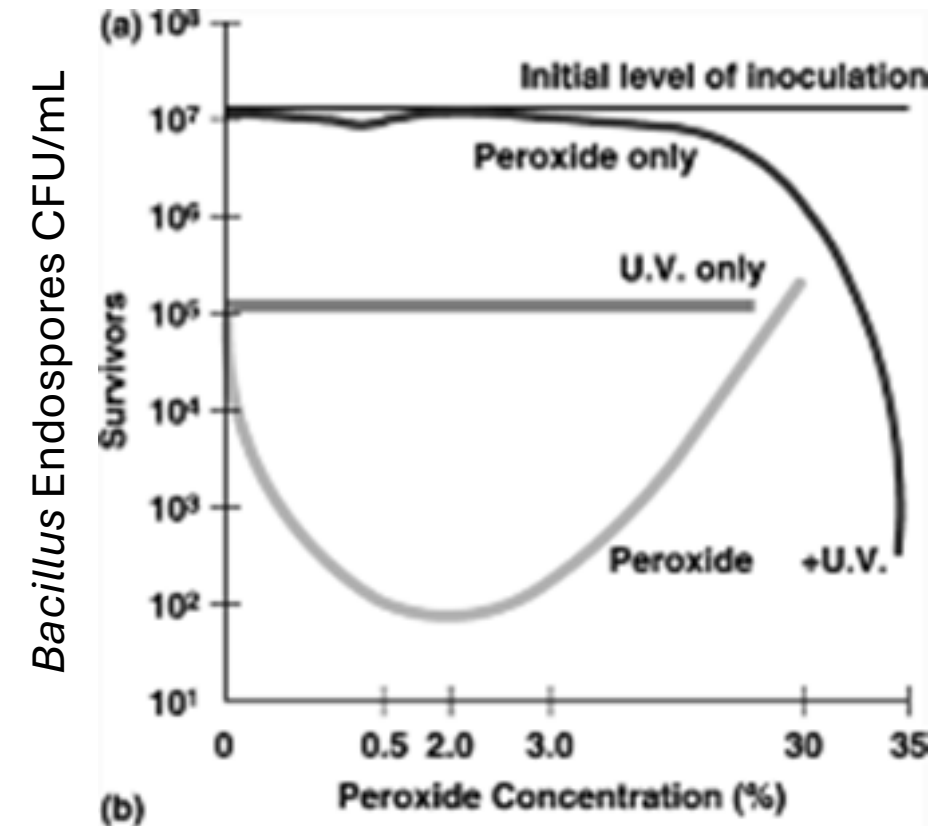
Initiation

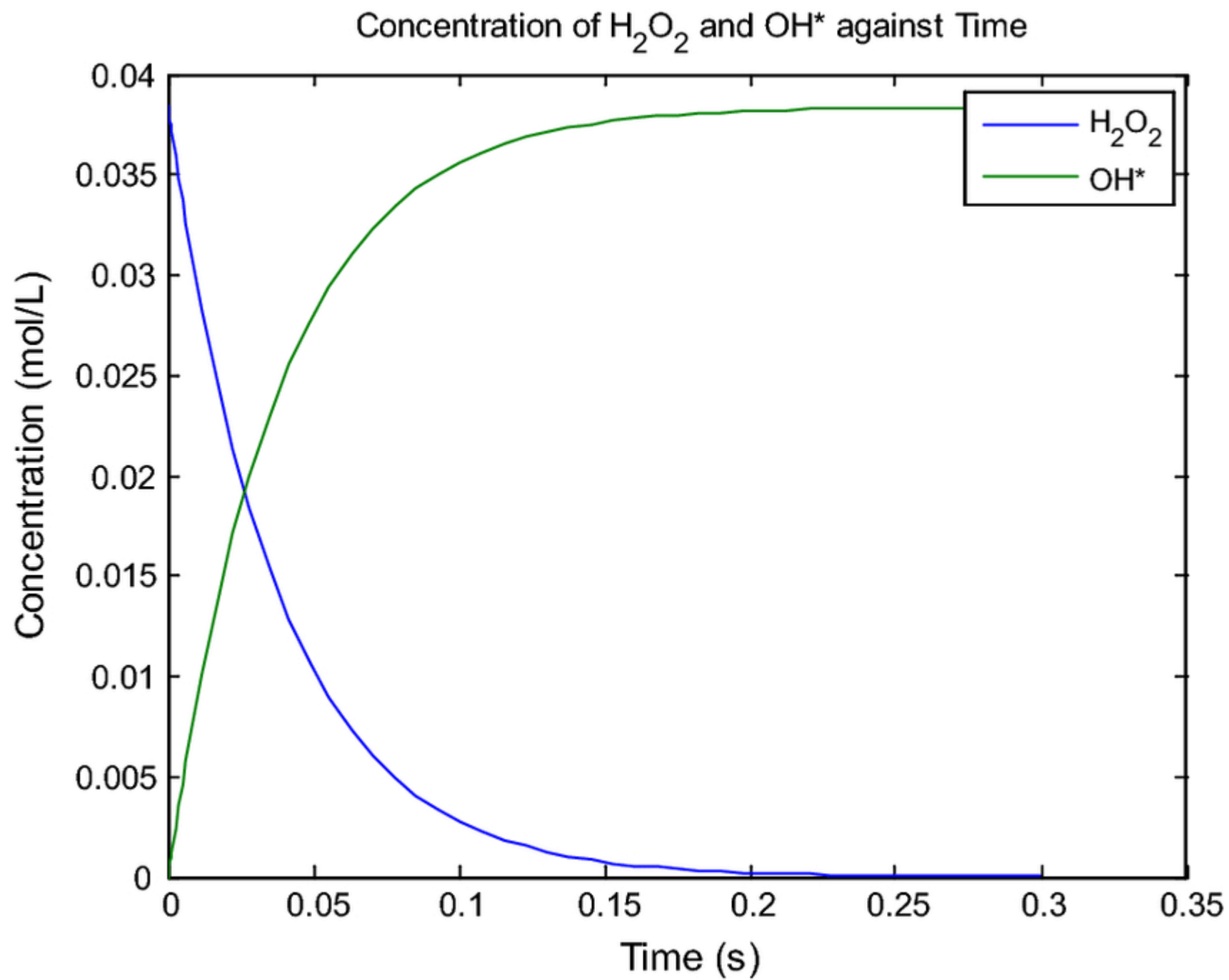


Propagation



Termination

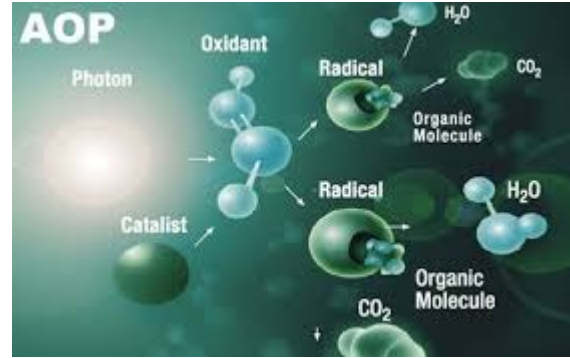




History of the Hydroxyl-radical Process



Henry Fenton
 $\text{H}_2\text{O}_2 + \text{Fe(II)}$
Fenton Reagent



Advanced Oxidation Process
Wastewater Treatment
 $\text{UV} + \text{H}_2\text{O}_2$



Elopak
Carton Sterilization
 $\text{UV} + \text{H}_2\text{O}_2$ vapor

1892



1979



1983

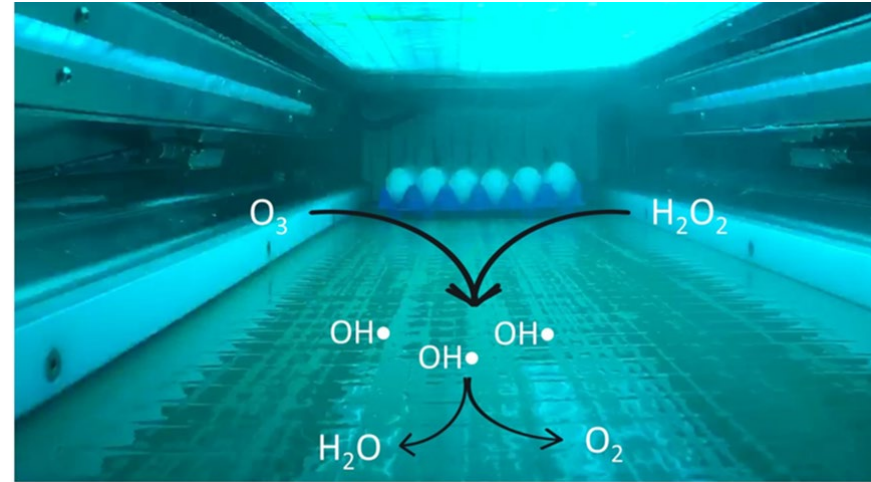


Radical processes

- Hydroxyl radical: Hydrogen peroxide and/or ozone
 - Chlorine radical: Hypochlorite
 - Sulfide radical: Thiocyanate
-
- Temperature (1 – 60°C): Increase yield with temperature
 - UV-C dose (60 – 400 mJ/cm²)
 - UV wavelength: 254 nm common 265 nm optimal
 - pH
 - Generation of hydroxyl-radical generation: Acidic pH
 - Reactivity: Alkali pH

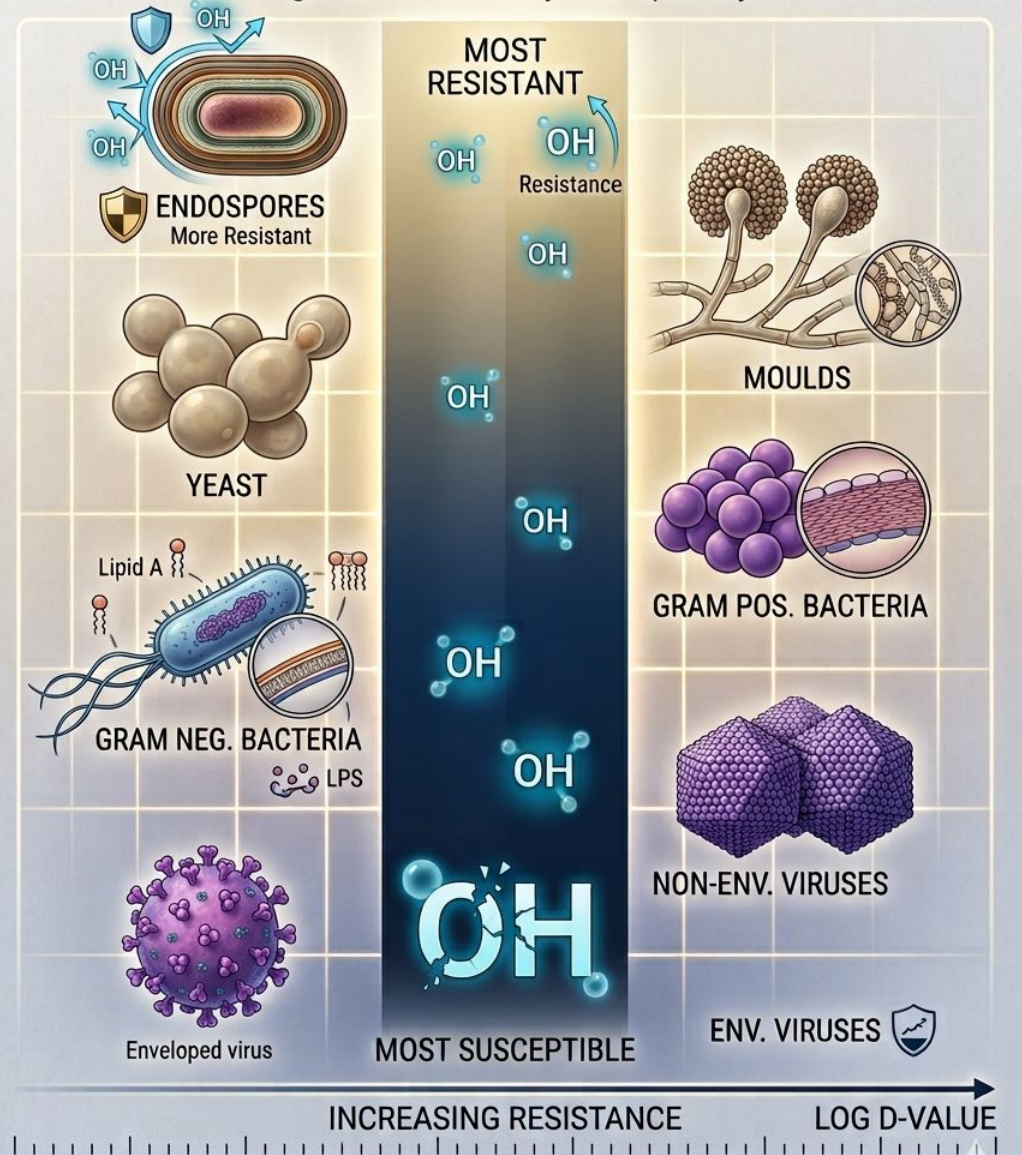
Hydroxyl-radical Process

- Gas phase
 - Transient
 - UV-C dose dependent
 - Greater antimicrobial capacity
- Aqueous phase
 - Greater stability
 - Propagation
 - Sequestered



MICROBIAL RESISTANCE HIERARCHY to Hydroxyl Radicals

Organisms Ranked by Susceptibility



KEY: OH = Hydroxyl Radical. Microbes are ordered on a directional logarithmic scale of resistance (D-values)

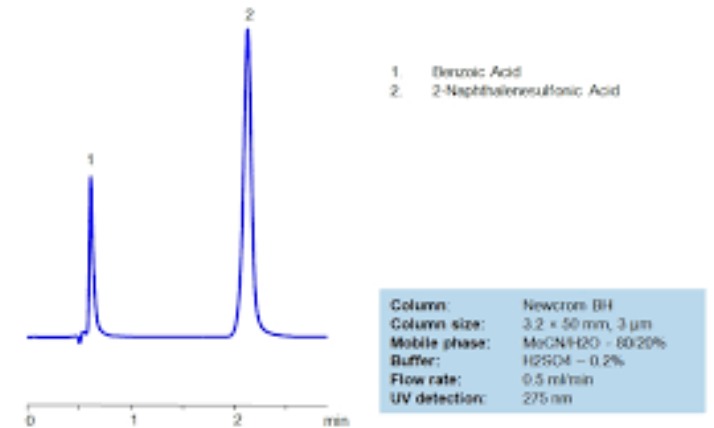
Surrogates

Pathogen/Specific Spoilage Microbe	Surrogate
<i>Toxigenic E. coli</i>	<i>E. coli</i> K12
<i>Listeria monocytogenes</i>	<i>Lactobacillus fructivorans</i>
<i>Salmonella</i>	<i>Enterococcus faecium</i>
Moulds	<i>Aspergillus niger</i>
Endospores	<i>Geobacillus stearothermophilus</i>

Measuring Hydroxyl-Radicals

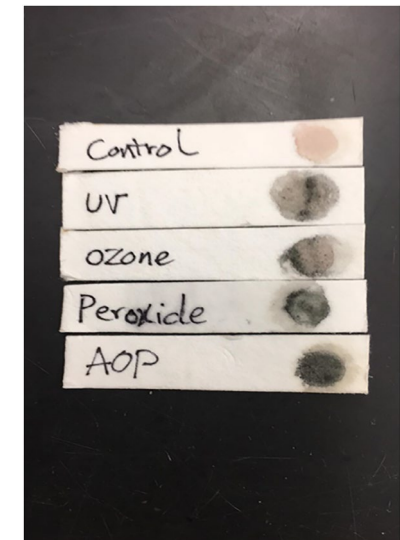
- Actinometry (chemical)

- Benzoic acid
- Nitrobenzene
- Methylene blue
- Pyrrole

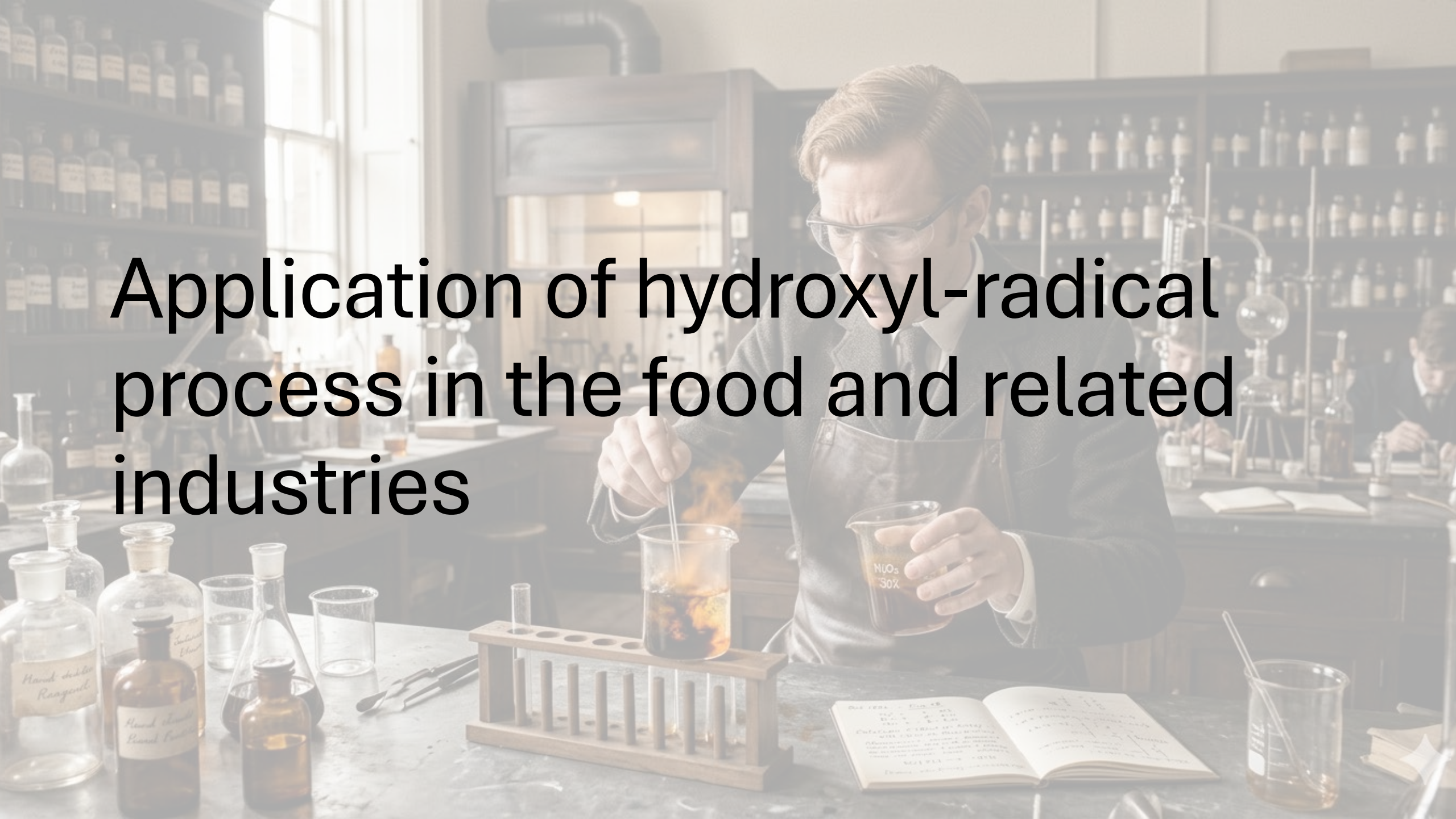


- Biodosimetry

- Molds (*Aspergillus niger*)
- Endospores (*Geobacillus sterothermophilus*)
- Bacteria (*Escherichia coli*, *Lactobacillus*)
- Bacteriophage (MS2)



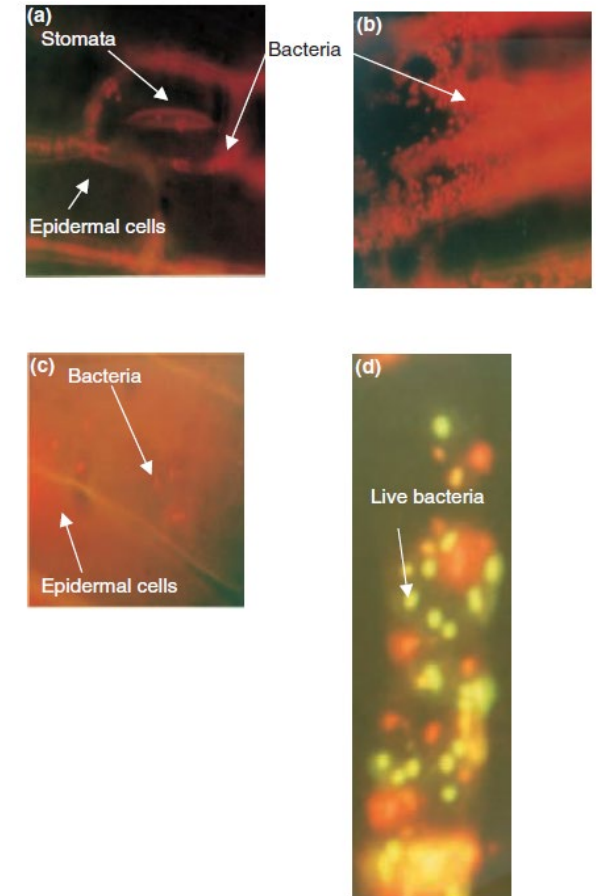
Application of hydroxyl-radical process in the food and related industries



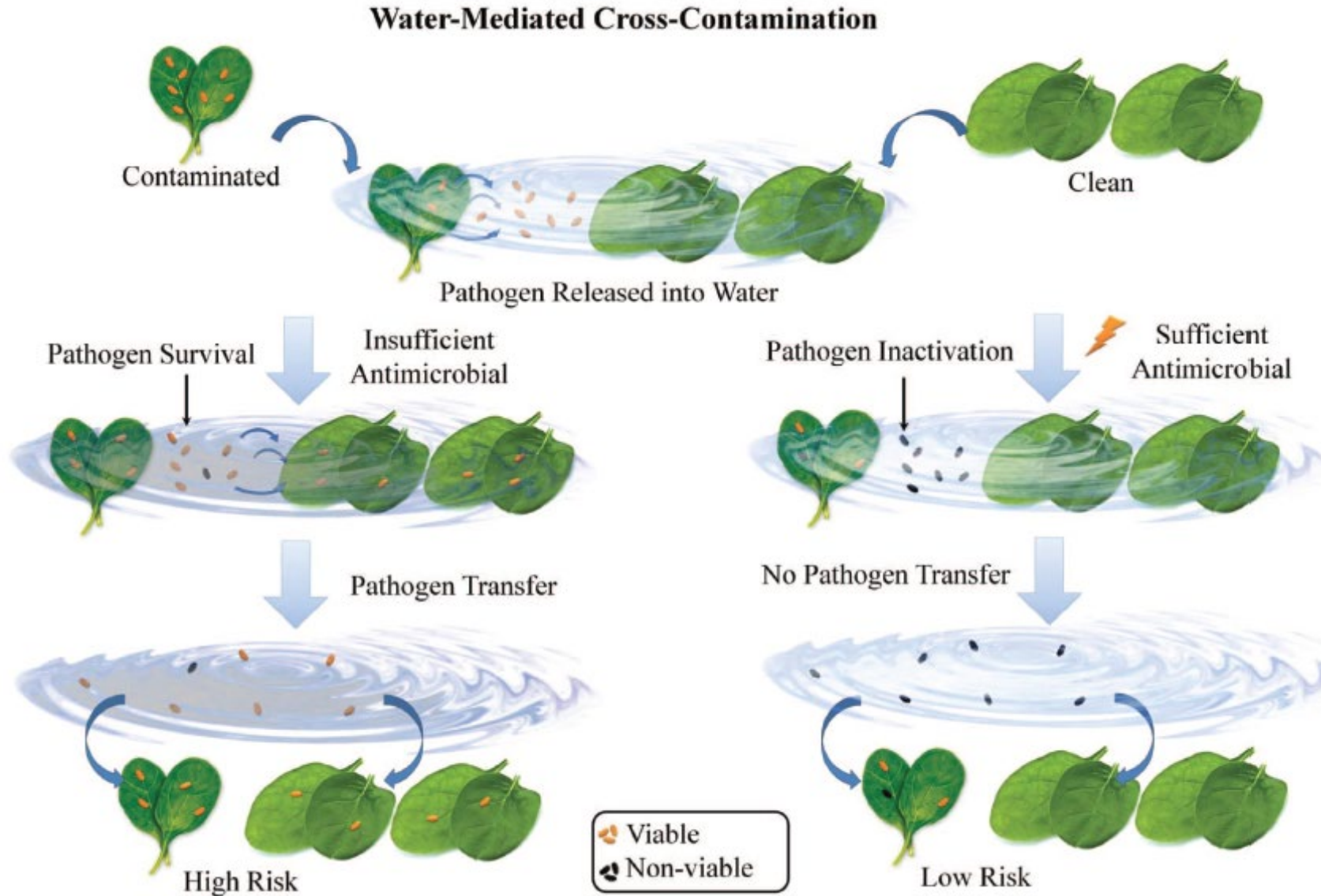
M&S (Research Partner: Why doesn't post-harvest washing work with reducing counts on spinach?)



1996



Cross-contamination during washing?

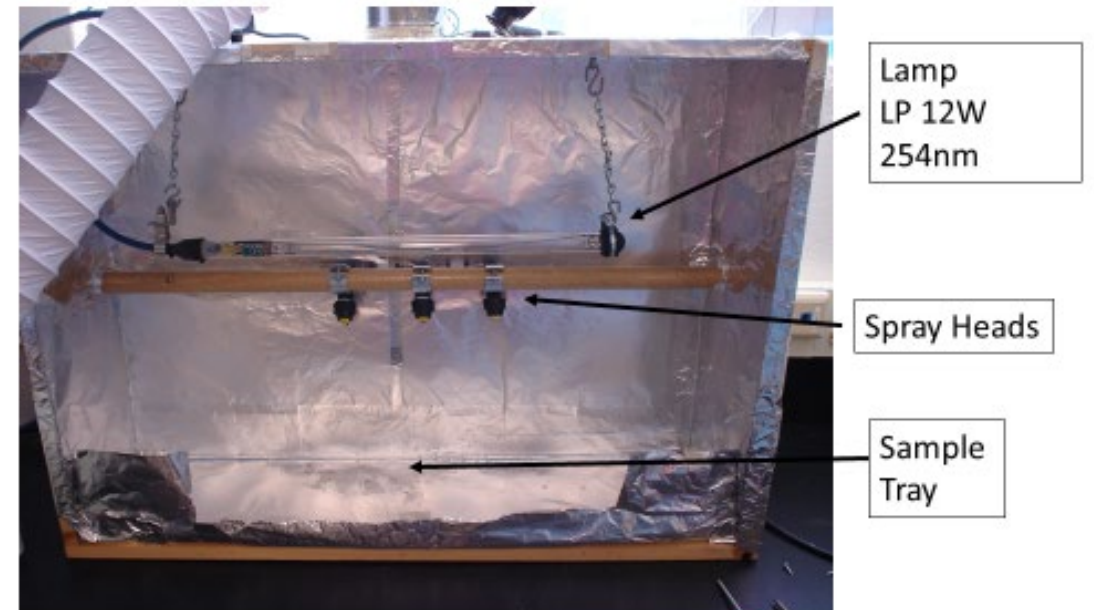


Attempt to prevent cross contamination.

Accept pathogens cannot be removed by washing

OMAFRA: UV and Hydrogen Peroxide – Decontamination of Fresh Produce

- Alternative to post-harvest wash
- Hydrogen peroxide spray
- UV-C lamp
- 30 second treatment



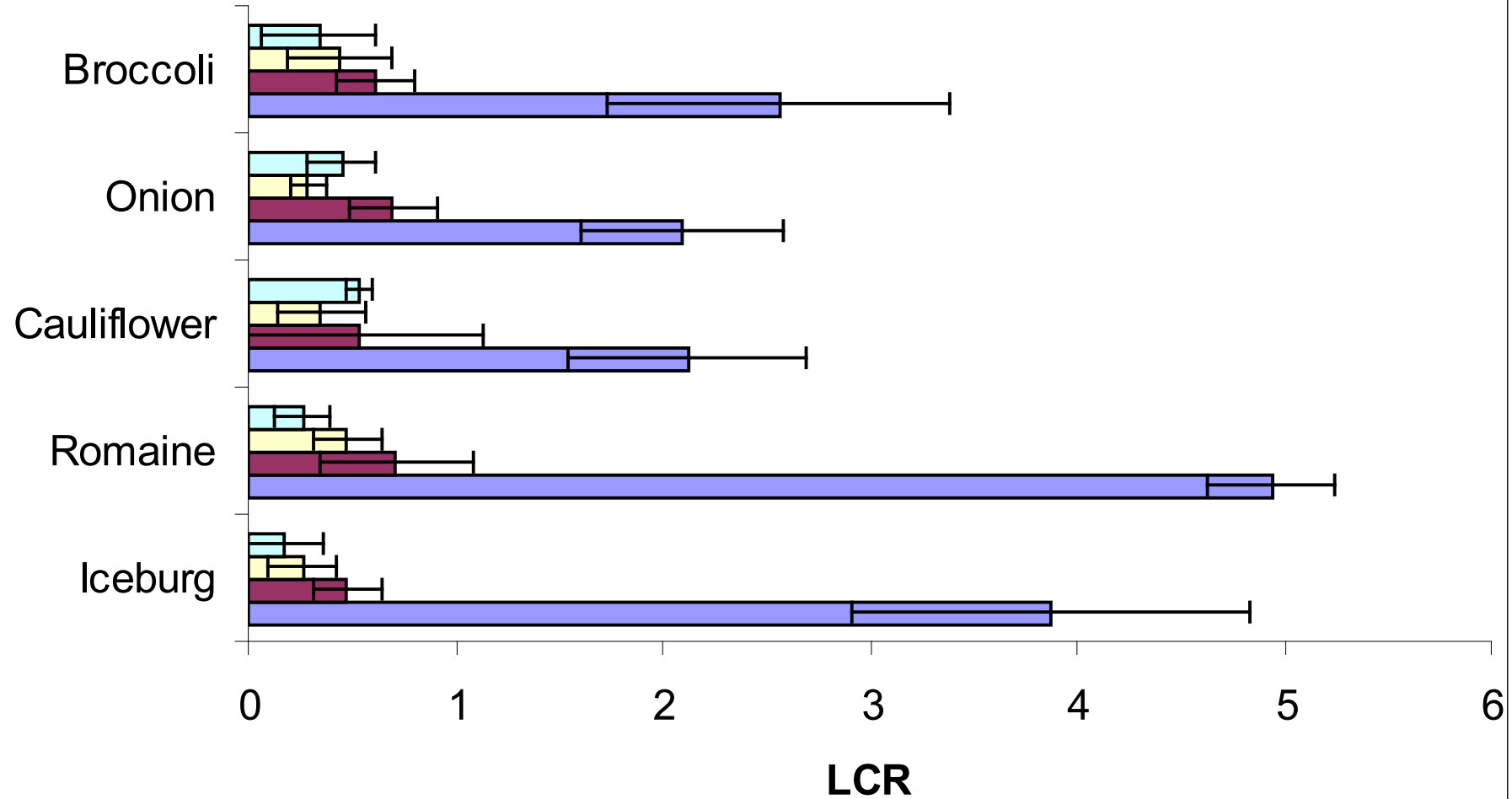
Journal of Applied Microbiology ISSN 1364-5072

ORIGINAL ARTICLE

Inactivation of human pathogens and spoilage bacteria on the surface and internalized within fresh produce by using a combination of ultraviolet light and hydrogen peroxide

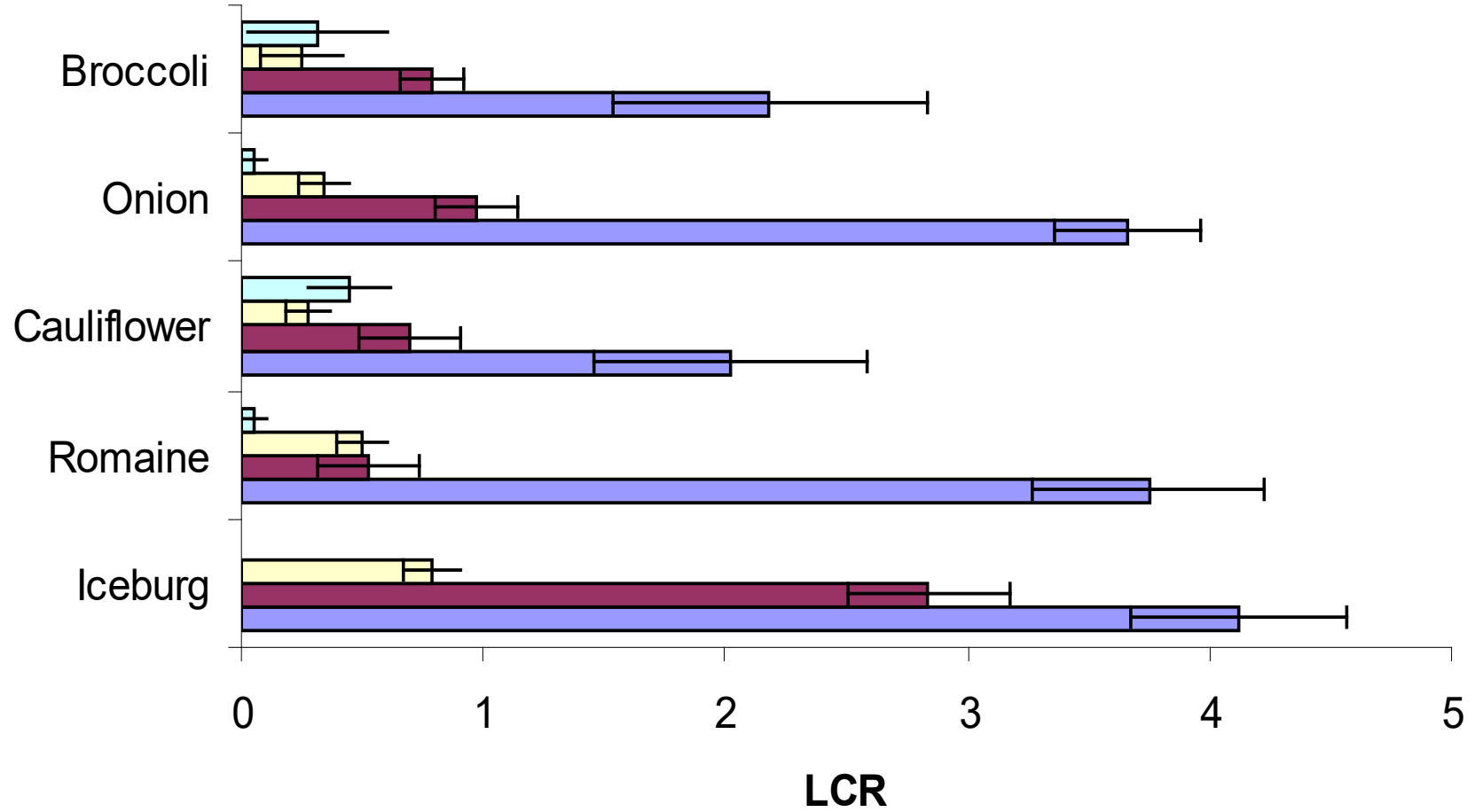
C. Hadjok¹, G.S. Mittal² and K. Warriner¹

E. coli O157:H7

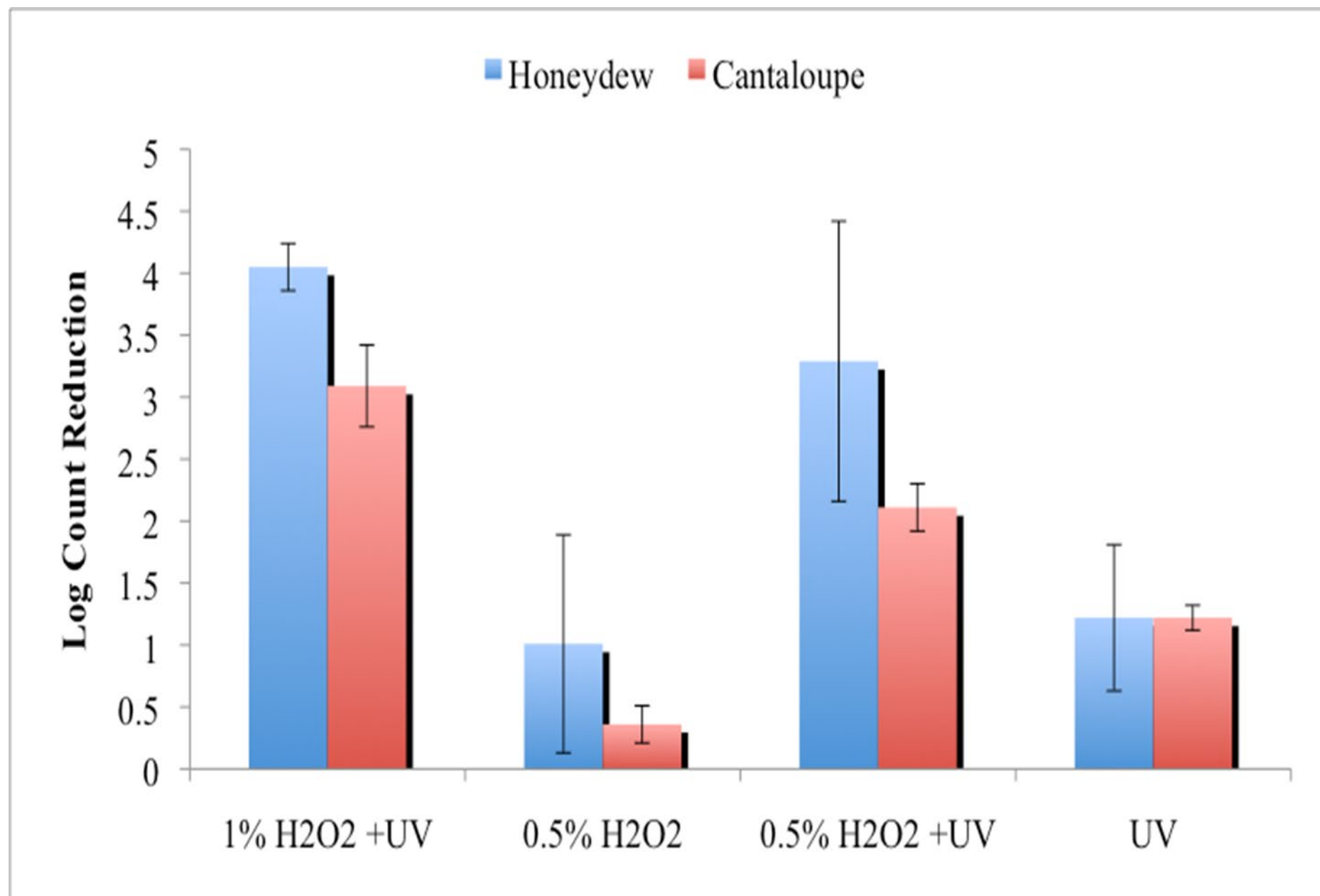


■ Surface (UV:H2O2) ■ Internal (UV:H2O2) ■ Surface (Hypo) ■ Internal (Hypo)

Salmonella



■ Surface (UV:H2O2) ■ Internal (UV:H2O2) ■ Surface (Hypo) ■ Internal (Hypo)



U of G Food Scientist Finds Effective Way to Clean Produce

May 18, 2006 – News Release

Buying prewashed lettuce can save you time, but it can also make you sick, as close to two dozen U.S. consumers discovered last year. Now University of Guelph food scientists have found a more effective way of cleaning vegetables that can dramatically reduce the risk of contamination.

2008

Journal of Food Protection, Vol. 71, No. 5, 2008, Pages 903–907
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Inactivation of MS2 F(+) Coliphage on Lettuce by a Combination of UV Light and Hydrogen Peroxide

Y. XIE,¹ C. HAJDOK,¹ G. S. MITTAL,² AND K. WARRINER^{1*}

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ORIGINAL ARTICLE

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Moyers Apple Products (Research Partner)



<https://youtu.be/e6iCTM8EEKg?si=WmBaAJjoooZri8JD>

Moyers Apple Products Est By Partnership between Moyers and Court Holdings (Research Partners)



Court Holdings Limited

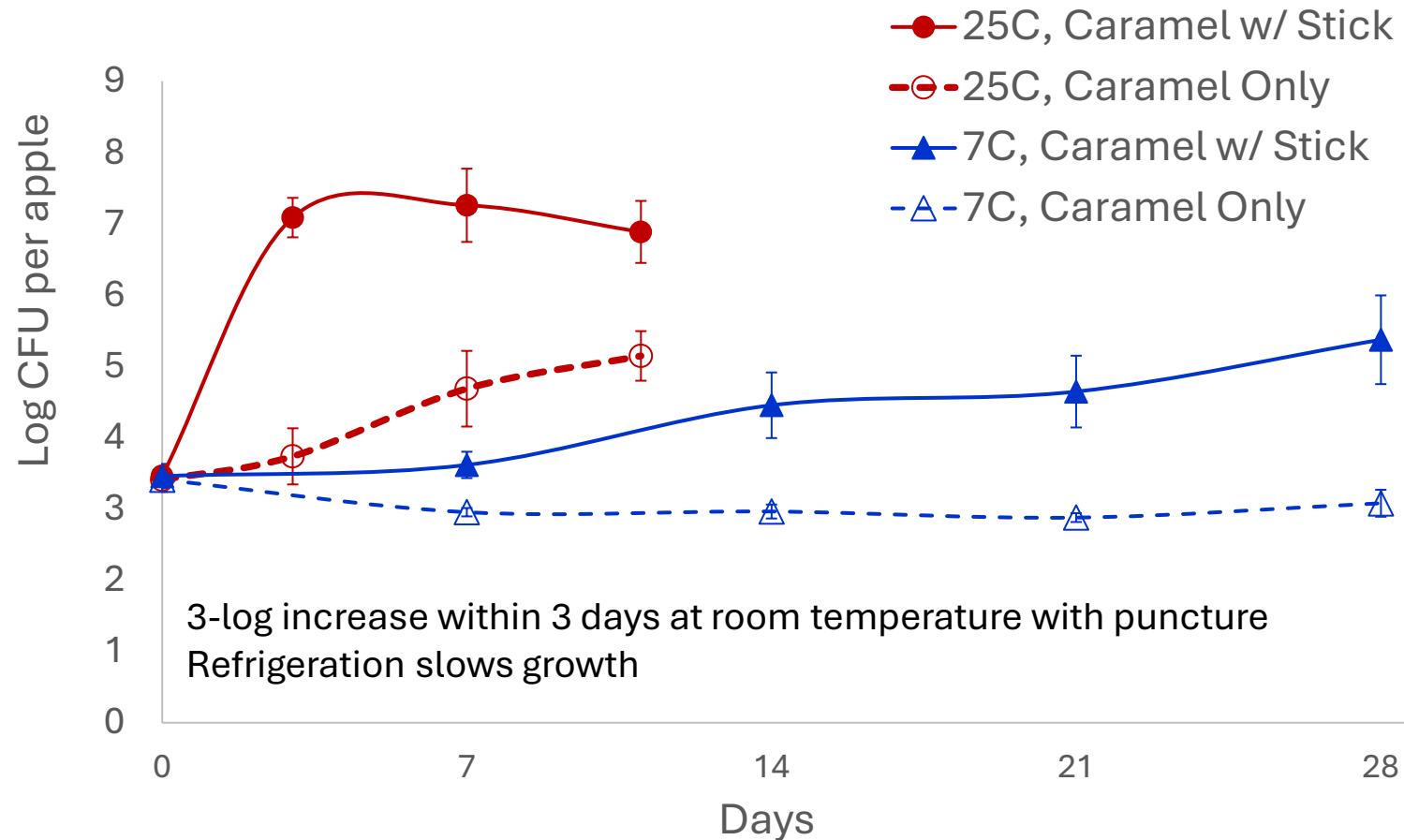


Granny Smith Apples 2015

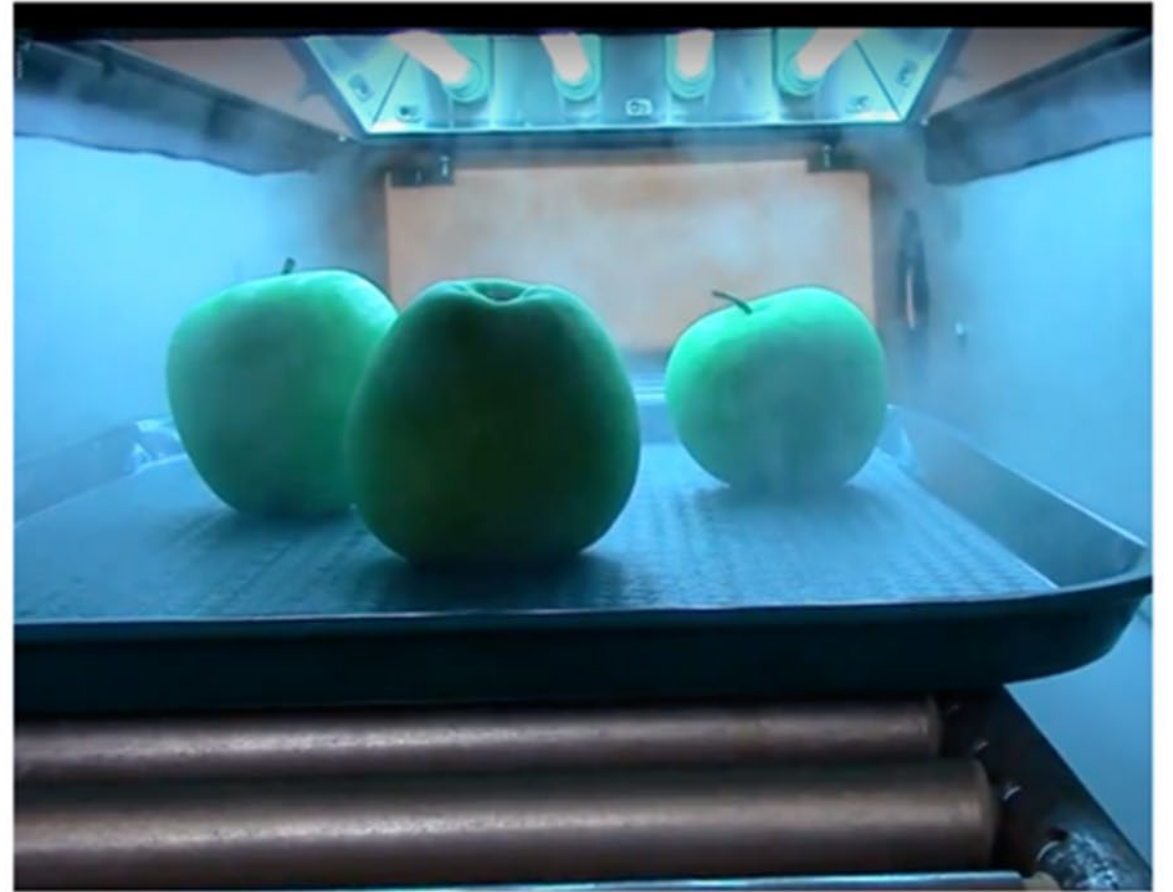
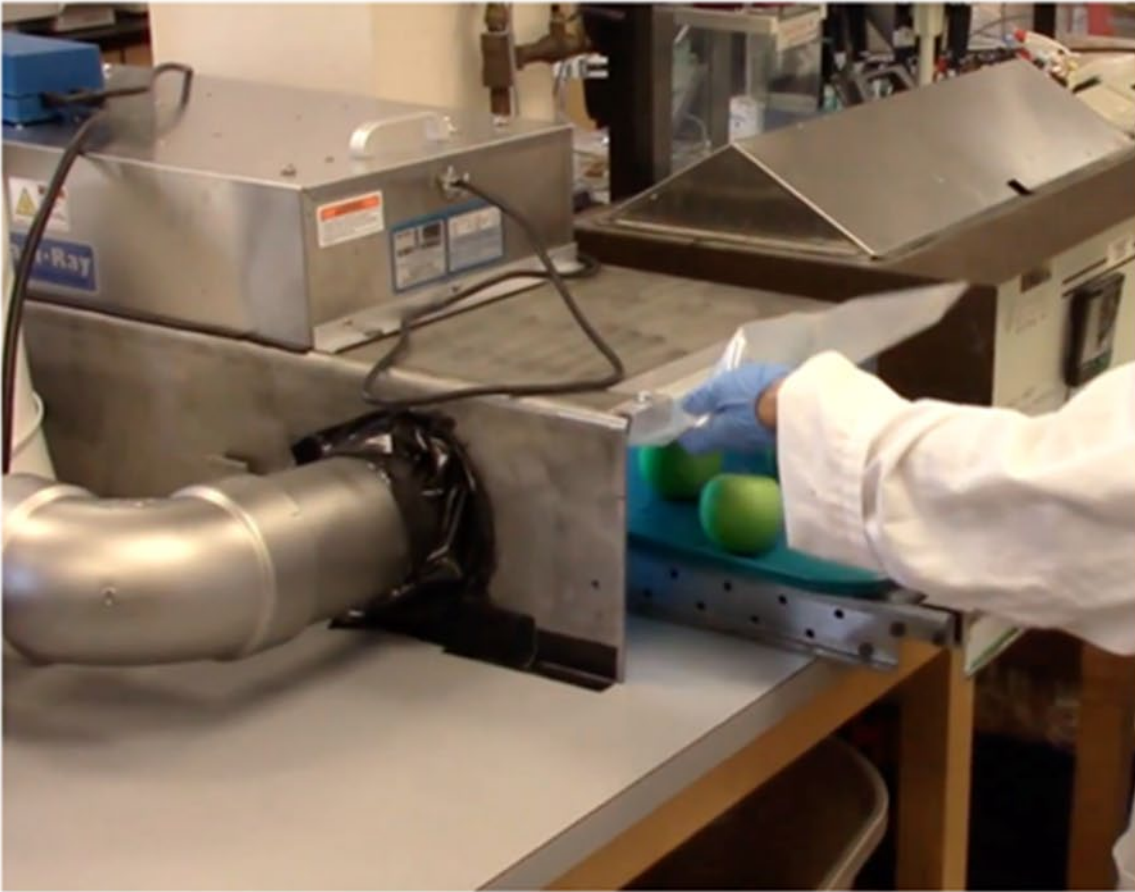
- California farm (Bidart Bros.): No conflict
- 12 states and Canada
- 35 cases (11 Pregnant)
- 7 deaths
- Apples
- Containers
- Processing area



Growth of *Listeria monocytogenes* on caramel-dipped apples Punctured w/ stick vs. no puncture



OMAFRA: Integrated Hurdles



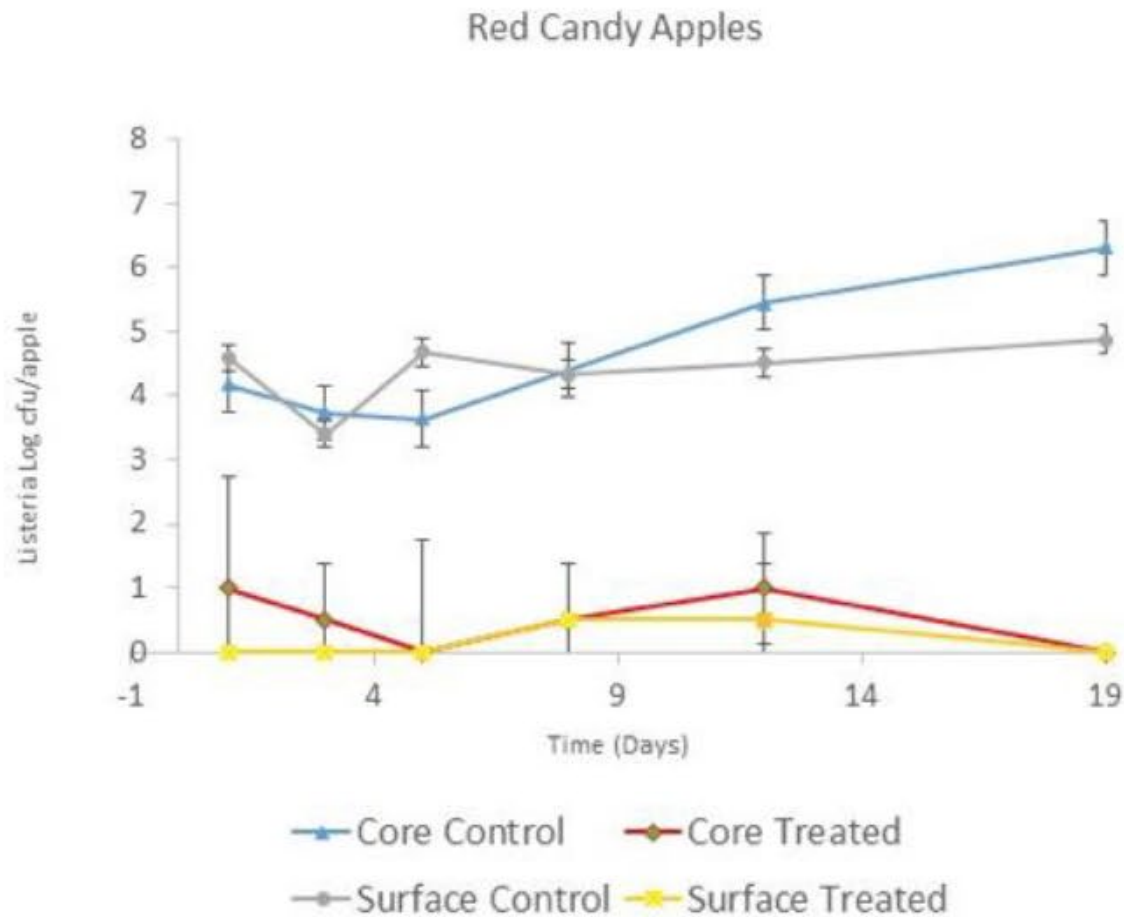
Combined Process

- Forced-air ozone 20 mins
- Hydroxyl-radical treatment
- Prepare caramel apples
- Store at 22°C

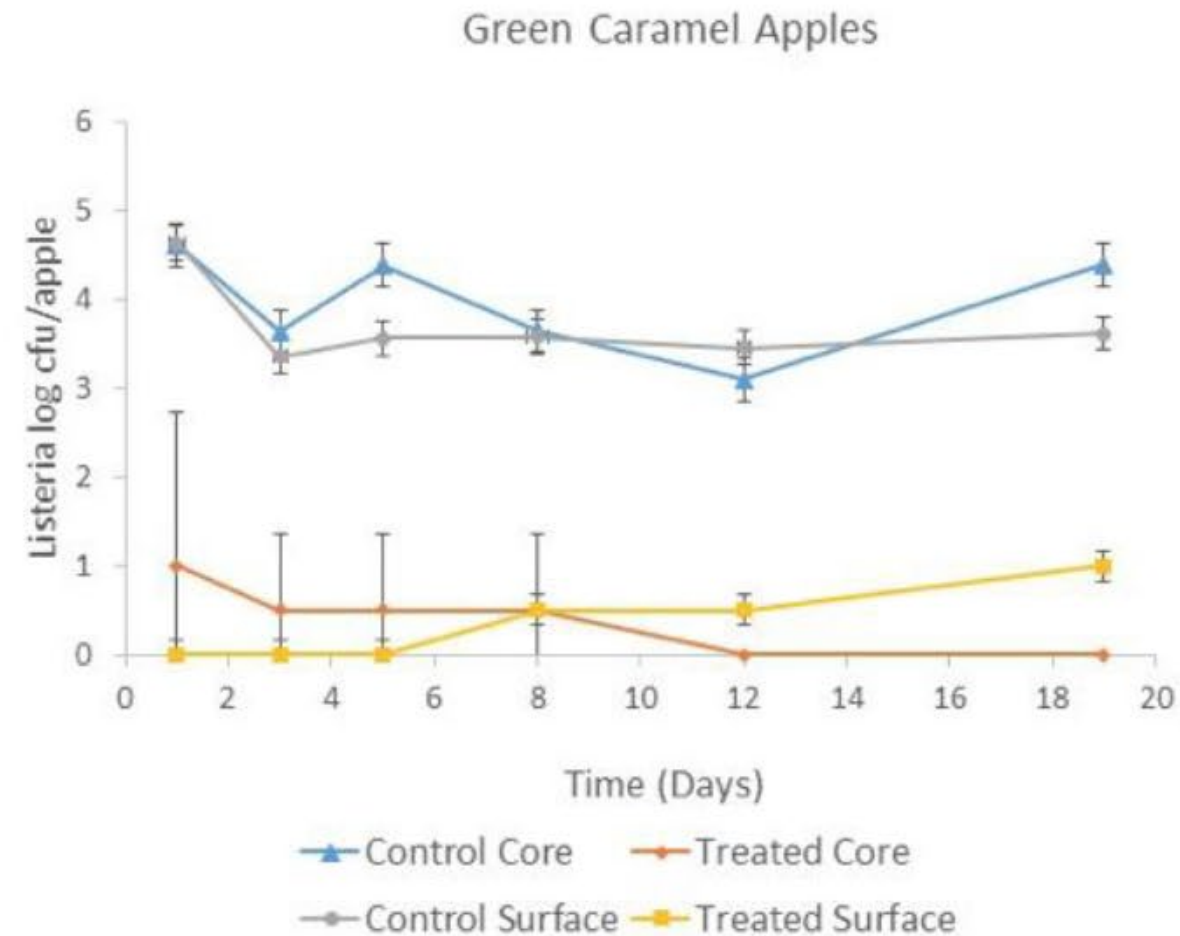


Storage of Candied Apples at 22°C

A



B



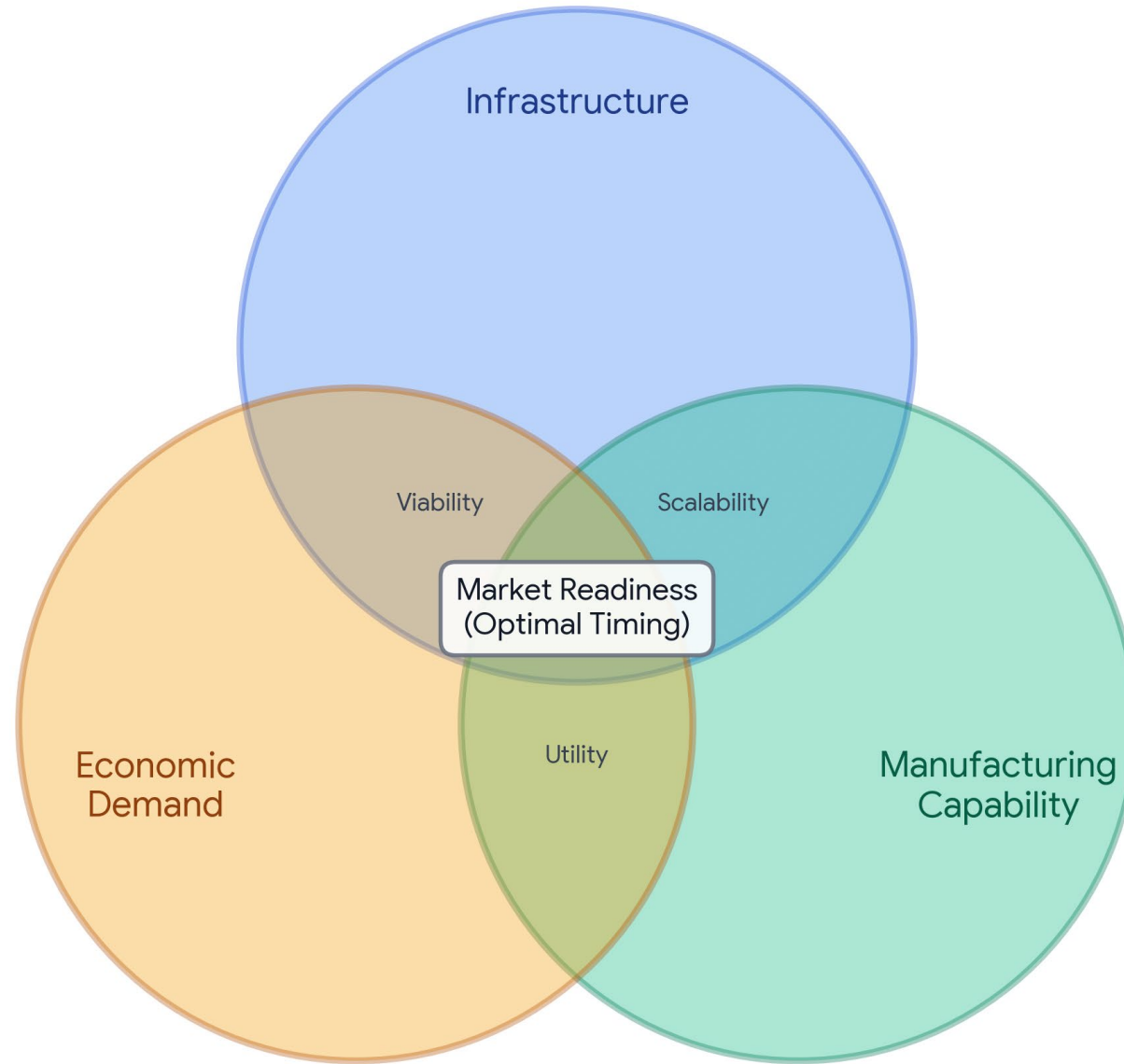
Food Safety is Competitive

Retailers –

- Did not want to devote refrigerator display space to candied apples
 - Assurance product is safe
 - Interventions that can be validated and monitored
-
- Increase demand
 - Distribute as far as Texas
 - Major retail chains



Anatomy of Invention Timing



SARS-CoV-2 (COVID 19)

HEALTH | News article

Experts downplay coronavirus fears despite Canada's first 'presumptive positive' case



Alexandra Mae Jones CTVNews.ca writer
@AlexandraMaeJ | Contact

Published Saturday, January 25, 2020 10:13PM EST



CTV National News: Coronavirus confirmed in Canada



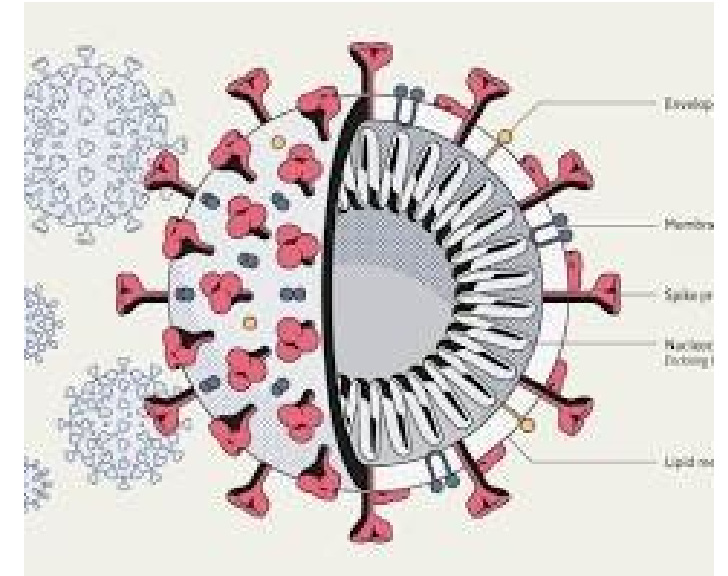
Officials have confirmed that a man in his 50s is the first 'presumptive case' of coronavirus. Jill Macyshon reports.

CTV National News: Can coronavirus be contained?



Infectious Disease Specialist Dr. Neil Rau discusses whether the virus can be contained and what to do if you are exposed to it.

A Call for PPE in the Fight Against COVID-19



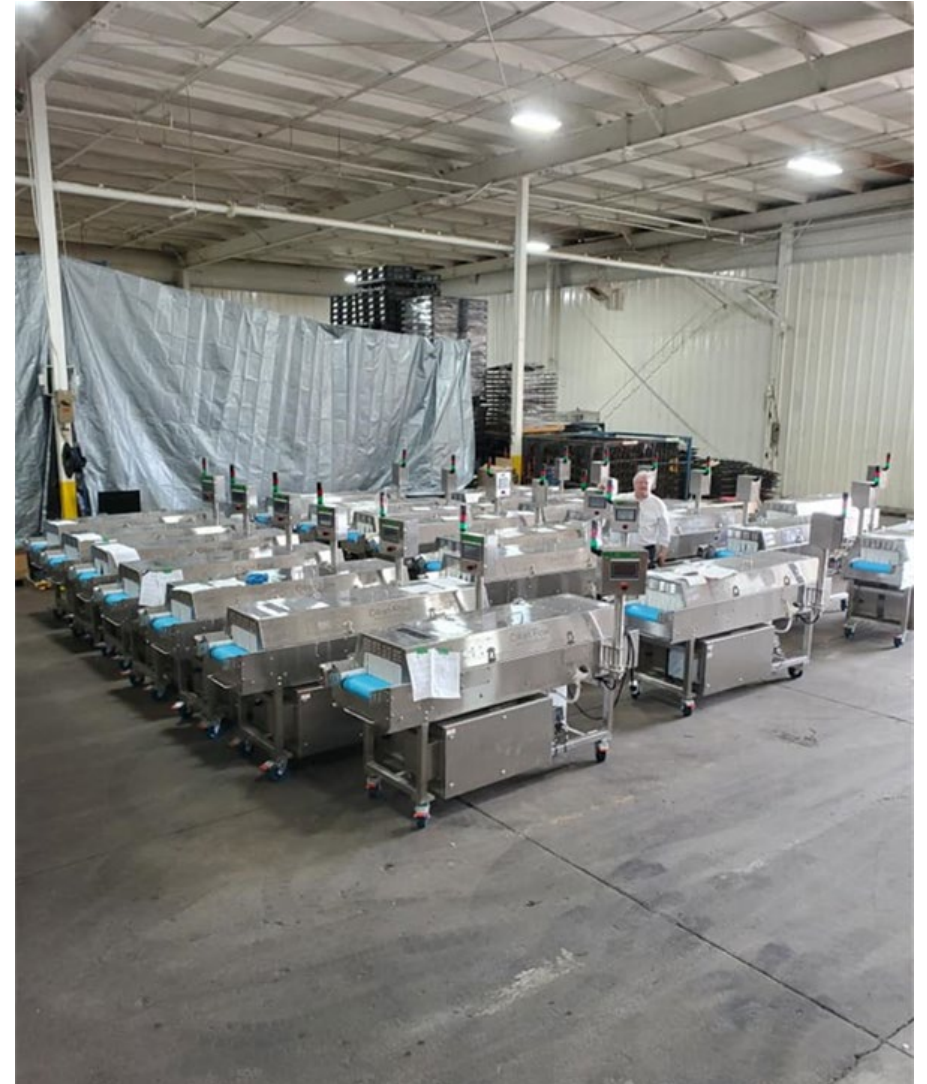
Regulatory Requirements

- Effective and consistent decontamination
- Defined operating parameter limits
- Applied to different PPE make & models
- No alternation to PPE function
- No toxic residues
- Occupational safety

Gas Phase Hydroxyl-Radical Reactor

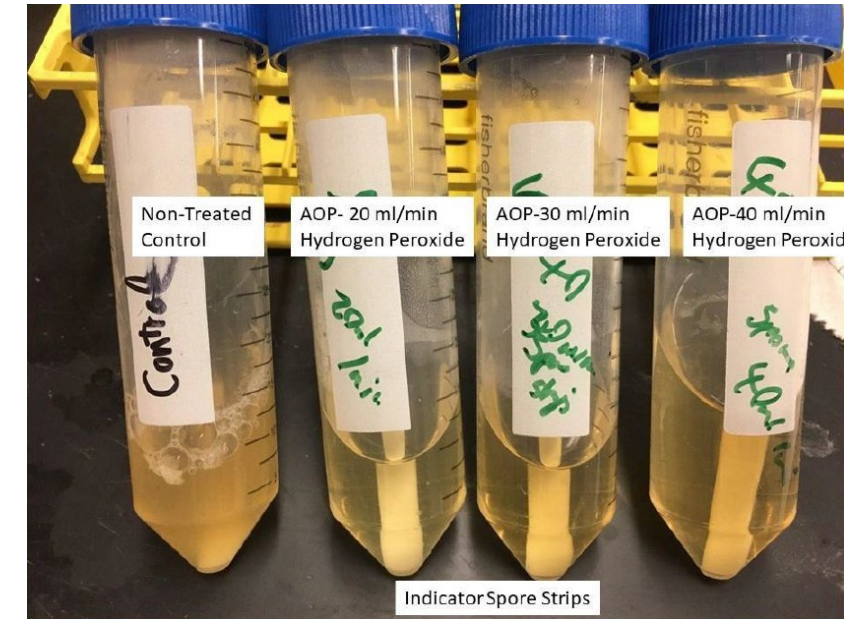
Operating parameters

- Hydrogen peroxide concentration and flow rate
- Ozone
- UV-C dose



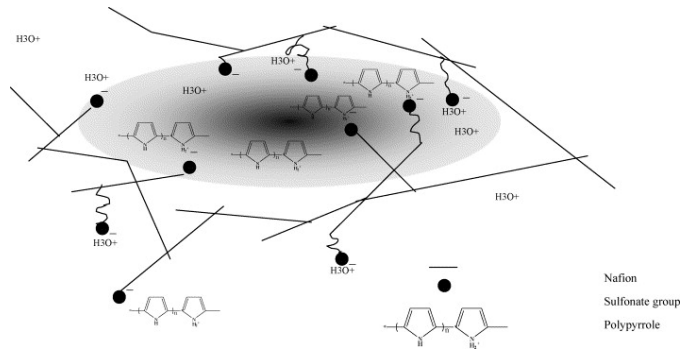
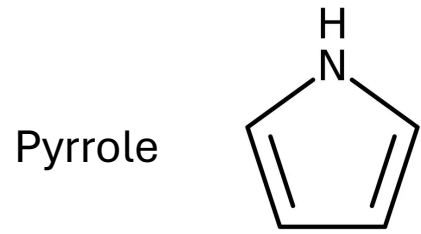
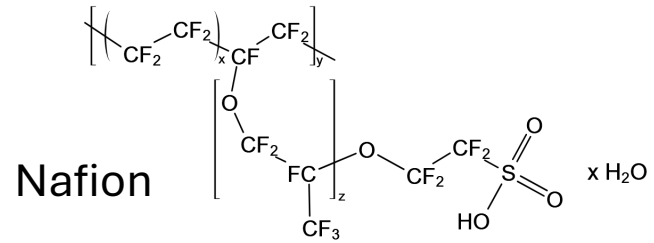
Sporicidal Treatment

- *Geobacillus stearothermophilus* endospores
- >6 log reduction
- Irradiation Indicator Strips (*Bacillus pumilis*)



Mask	Hydrogen peroxide Flow Rate	Log cfu (#Positive by enrichment/Total Tested)	Log Count Reduction
Initial Loading		6.19±0.05	
AOP (inside)	40 ml/min	Negative	6.19
AOP (outside)	40 ml/min	Negative	6.19

Chemical Indicator



Polypyrrole



<https://youtu.be/7qkkioZXXzw?si=gpaiXi0ADJc5bdCp>

Approved Medical Device

Health Canada Approval

N95 masks and other PPE

Consistent sterilization (6 log CFU

Geobacillus stearothermophilus endospores

Retain functionality

No residues or byproducts

April 13th 2020

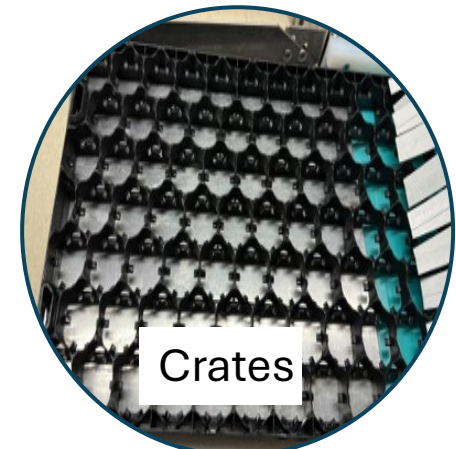
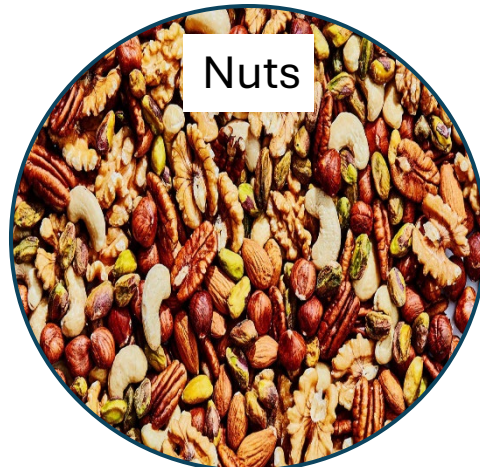
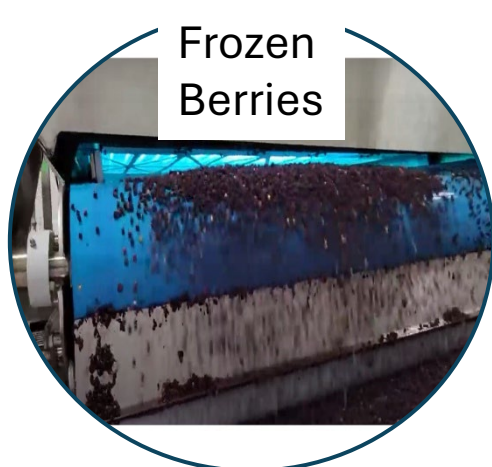
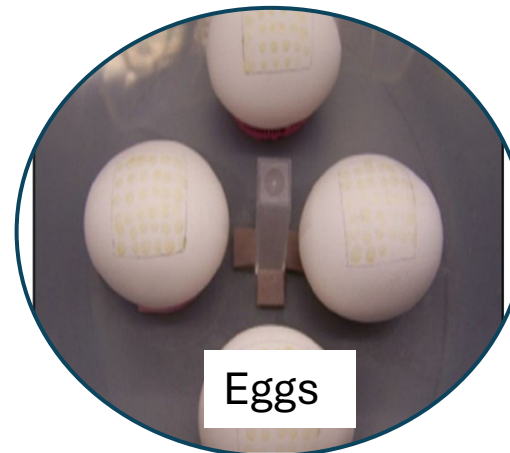
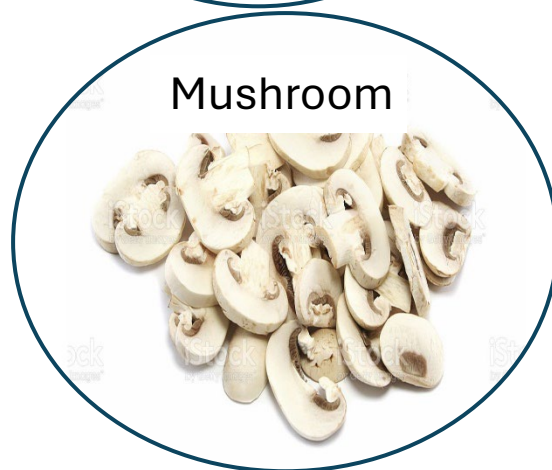
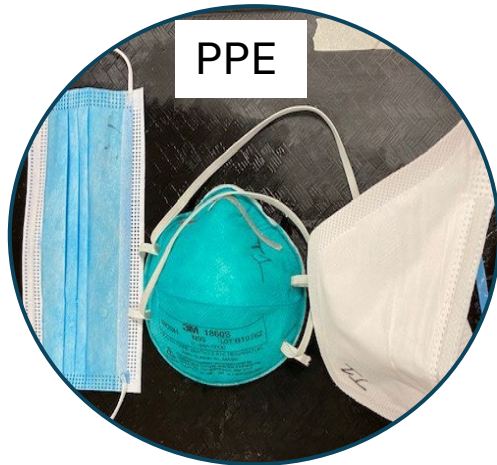
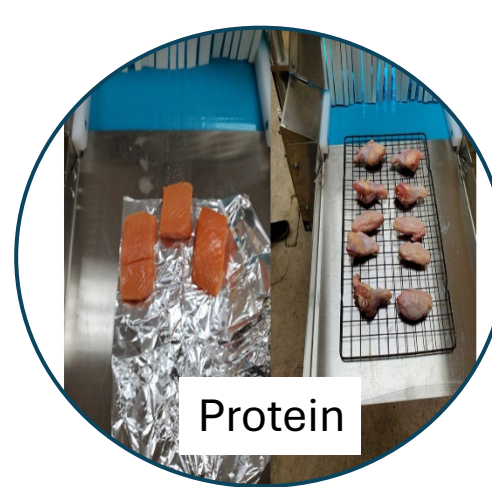
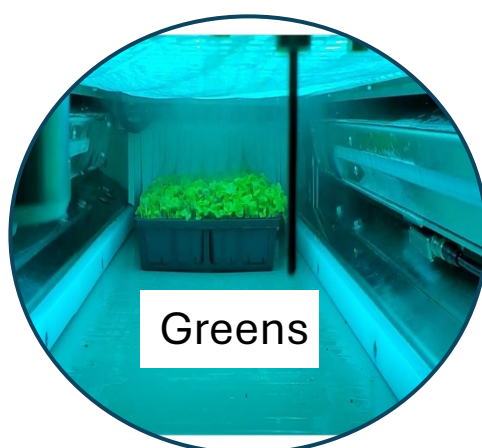
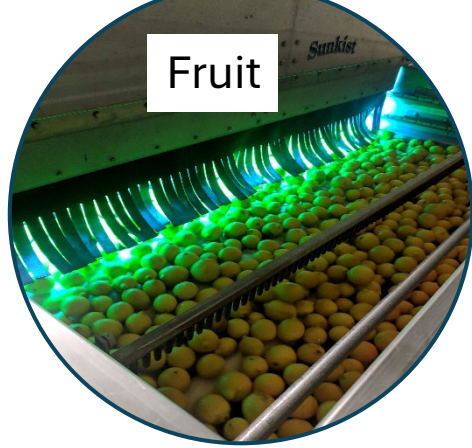
 Health Canada Santé Canada		Medical Devices Directorate Direction des instruments médicaux	
<u>COVID-19 Medical Device</u> <u>Authorization for Importation or</u> <u>Sale</u>		<u>Autorisation d'importation ou de</u> <u>mise en vente d'un instrument</u> <u>médical relatif au COVID-19</u>	
Authorization Reference Number : 313709		Numéro de référence de l'autorisation	
Issue Date: 2020-04-13		Date de délivrance:	
Device Class/Classe de l'instrument : 2			
Pursuant to section 5 of the Interim Order Respecting the Importation and Sale of Medical Devices for Use in Relation to COVID-19, made by the Minister of Health on March 18, 2020, the medical device listed below is now authorized for sale or importation in Canada. Each shipment of a COVID-19 medical device that is imported into Canada must be accompanied by a copy of this authorization document. This authorization is only valid for so long as the Interim Order Respecting the Importation and Sale of Medical Devices for Use in Relation to COVID-19 is in effect.		Conformément à l'article 5 de l'Arrêté d'urgence concernant l'importation et la vente d'instruments médicaux relatifs au Covid-19, réalisé par la ministre de la Santé le 18 mars 2020, les instruments indiqués ci-dessous sont présentement autorisés pour la mise en vente ou l'importation au Canada. Tout envoi d'un instrument médical relatif au COVID-19 doit être accompagné d'une copie de la présente autorisation. Cette autorisation est uniquement valide tant que l'Arrêté d'urgence concernant l'importation et la vente d'instruments médicaux relatifs au Covid-19 est en vigueur, ou l'autorisation est annulée.	
Device Name(s) Nom de l'instrument CLEAN FLOW HEALTHCARE MINI			
Name & Address of Authorization Holder/Nom & adresse du titulaire de l'autorisation CLEAN WORKS MEDICAL 4758 CHRISTIE DRIVE BEAMSVILLE, ONTARIO CANADA L0R 1B1			
David Boudreau, ing., Interim Director General, Medical Devices Directorate Directeur général par intérim, Direction des instruments médicaux 			
Application Number: Numéro de la demande: 313709		Manufacturer ID: Identificateur du fabricant: 153043	

Decontamination of boxes and pallets



Hydroxyl-radical process for decontaminating reusable bags and surgical gowns

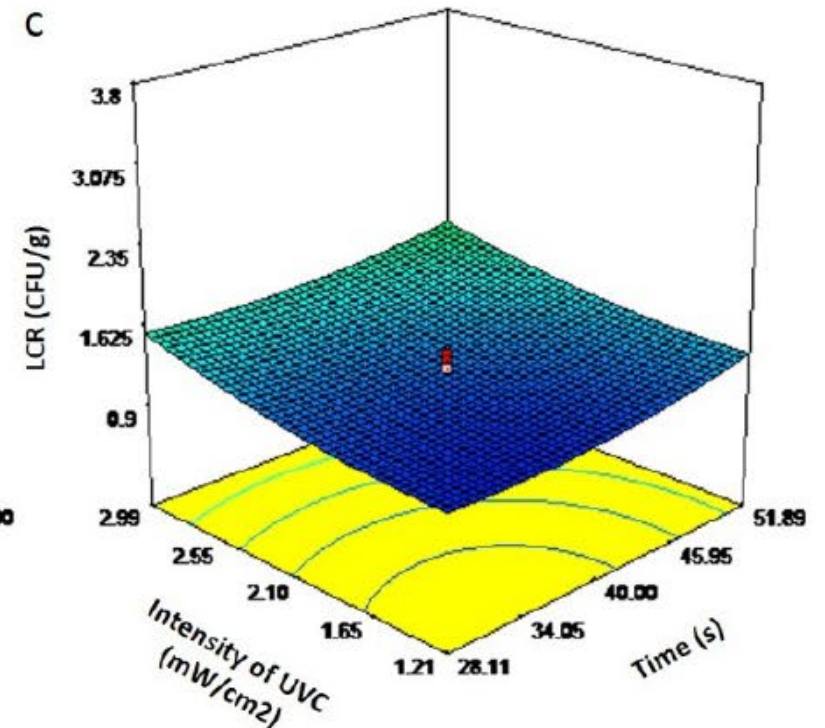
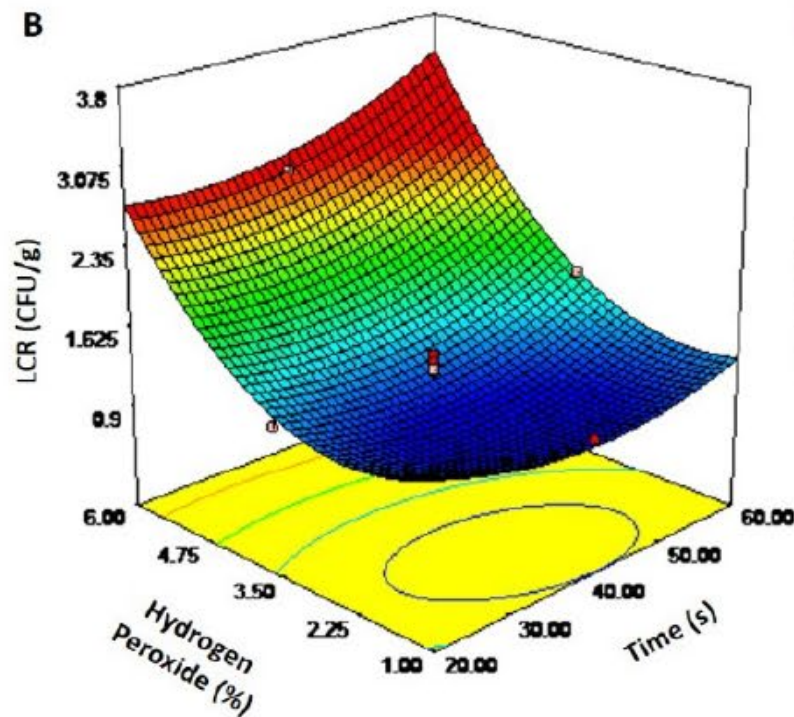
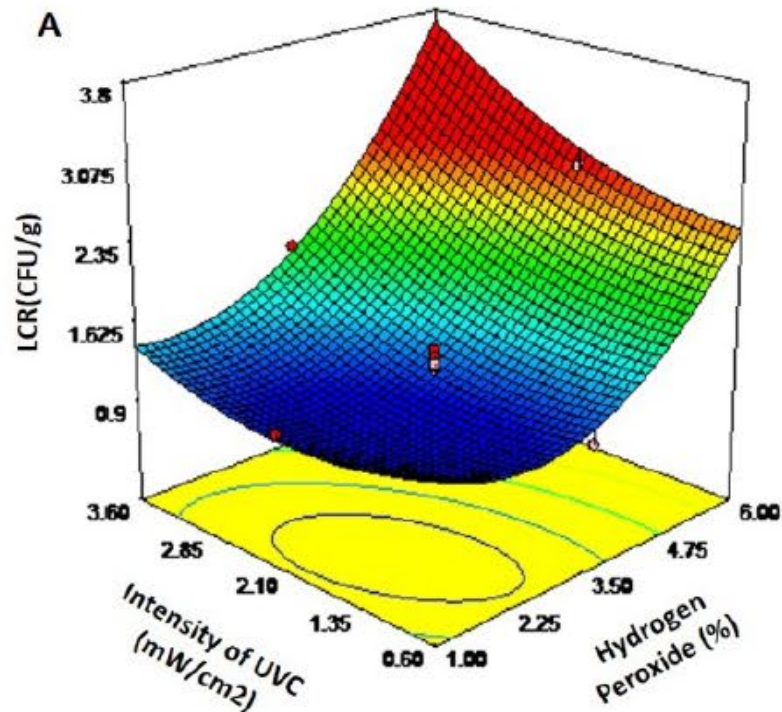




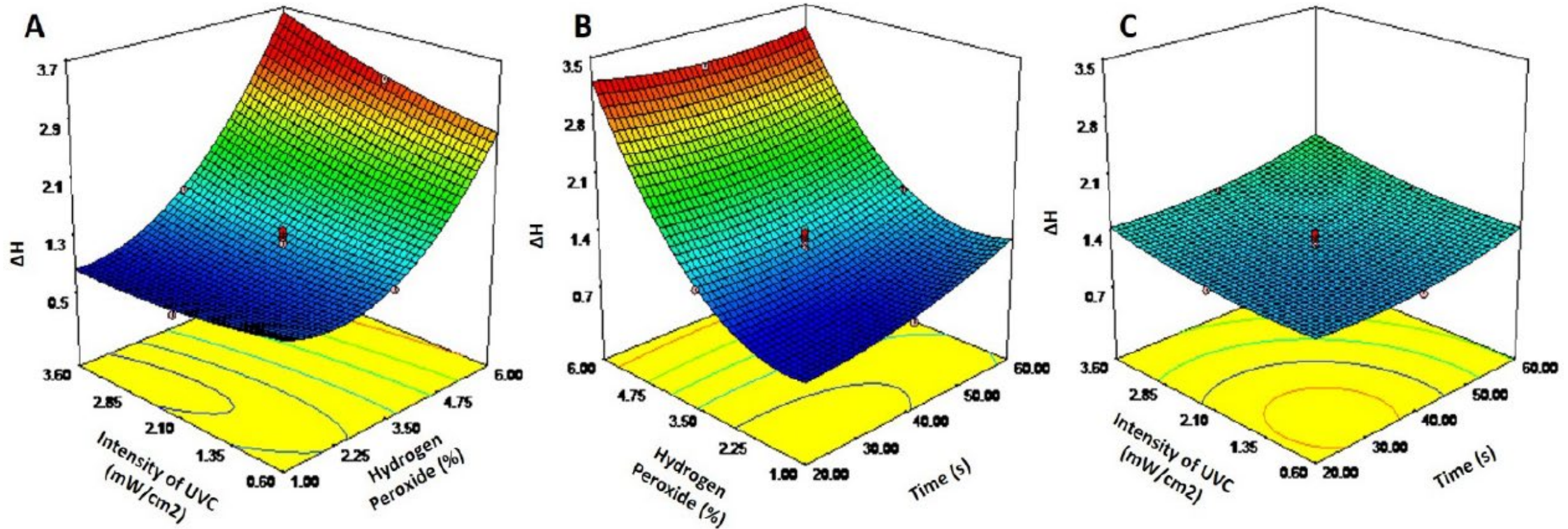
AOP Treatment for Lemons



Response Surface Modelling: Log count reduction *Aspergillus niger* spores



Change in Lemon Color: Optimization of Treatment Parameters



Shelf-life Extension: Tangible benefit

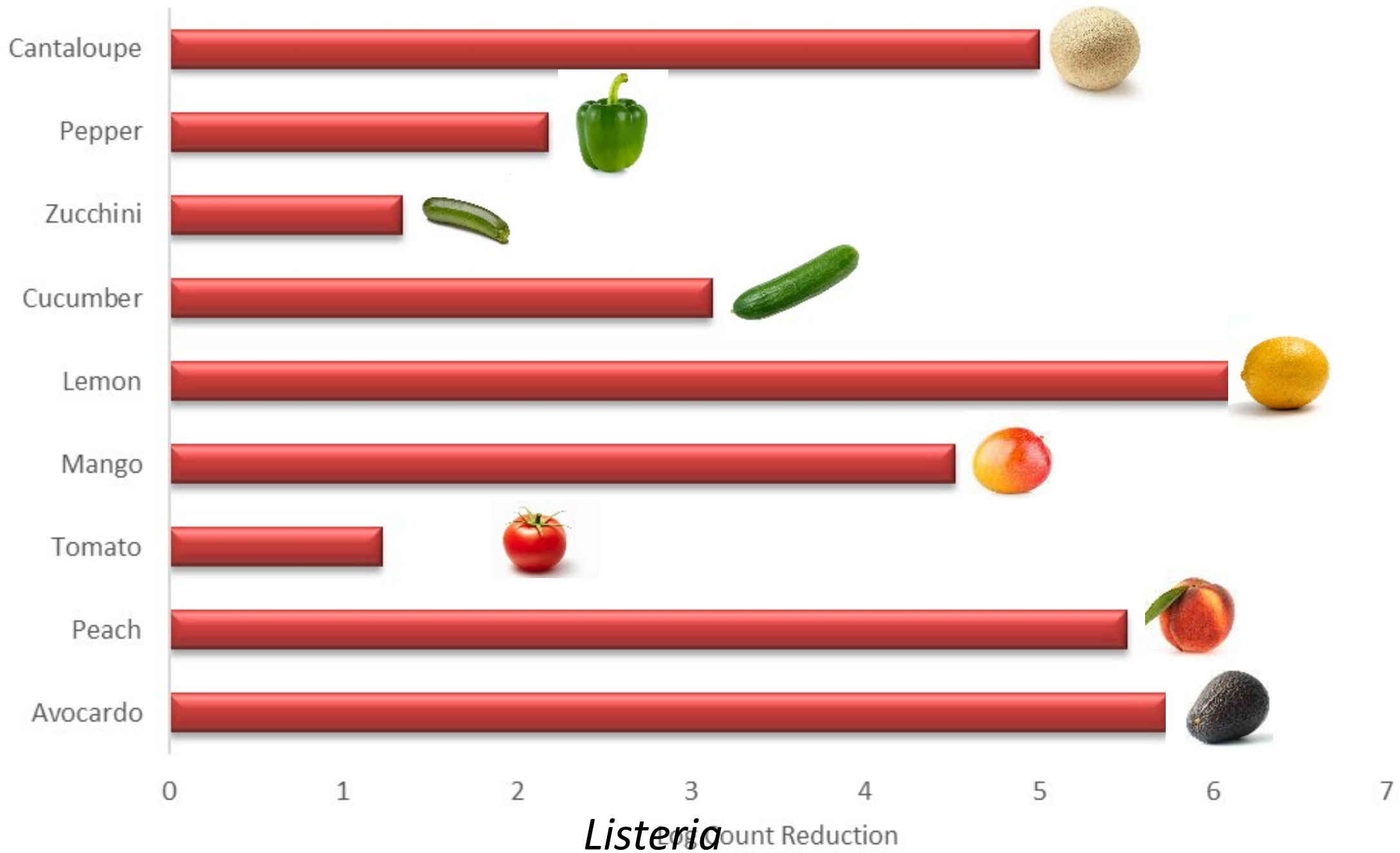


Peaches Day 1

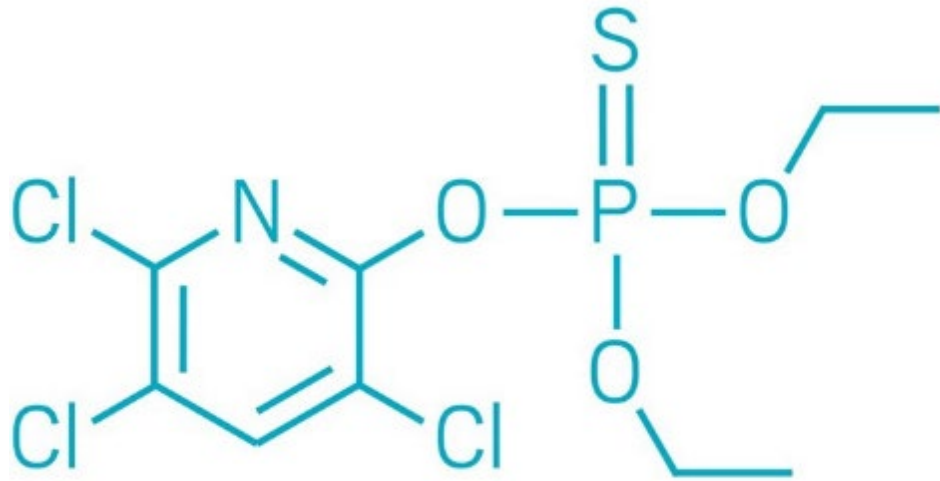


Peaches Day 9

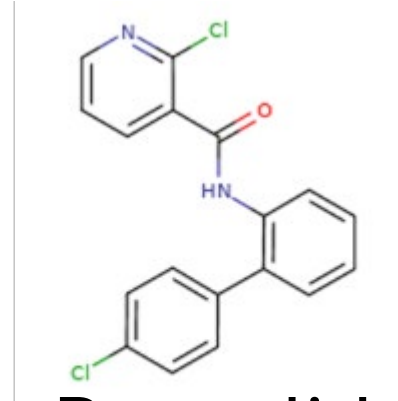




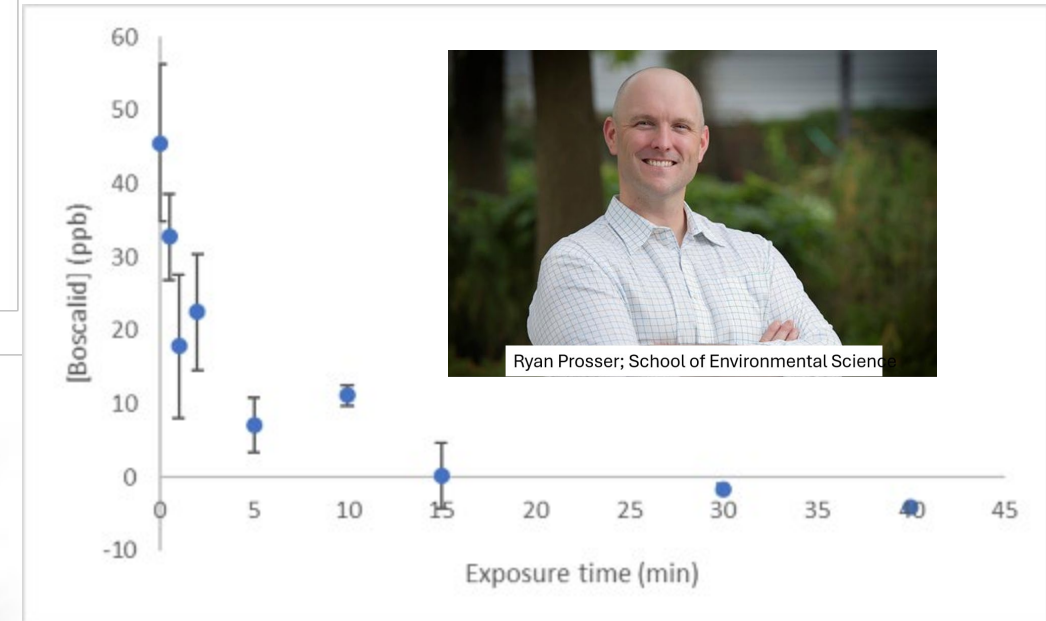
Pesticide degradation on fruit by Hydroxyl Radical Process



Chlorpyrifos



Boscalid

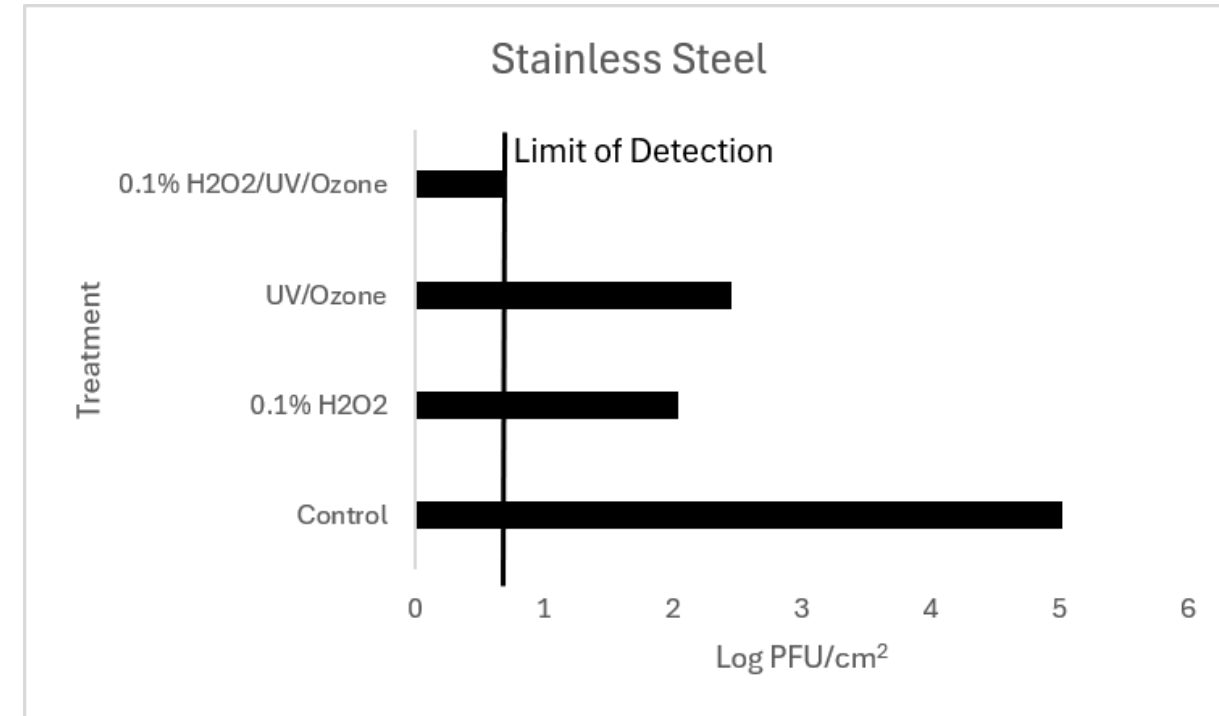
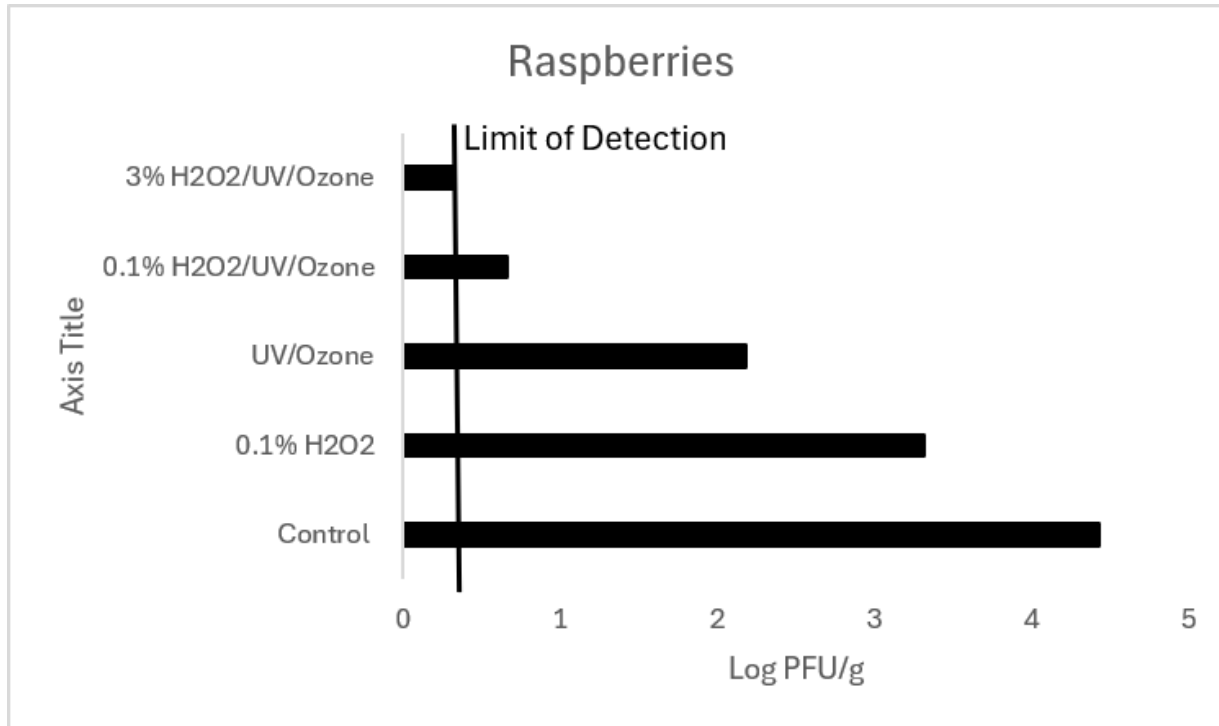


Clean flow benchtop unit

- 4 UV-C lamps (21 W; 254 nm)
- Ozone lamp (15 W; 185 nm)
- Hydrogen peroxide mist (8 μ m droplets; 2.5mL/min)

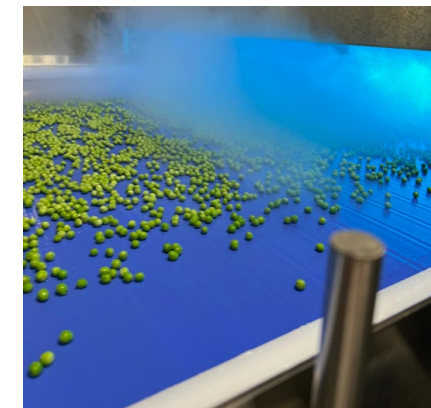
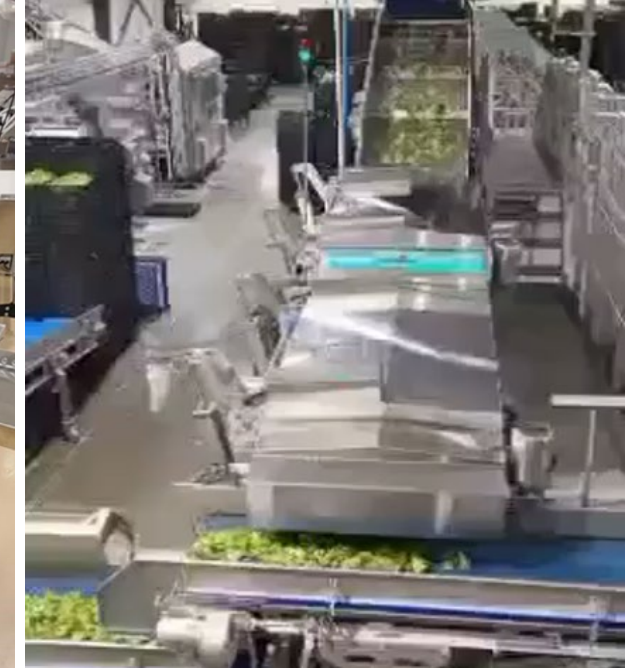


Murine Norovirus



UV-C dose = 225 mJ/cm² Ozone: 20 ppm

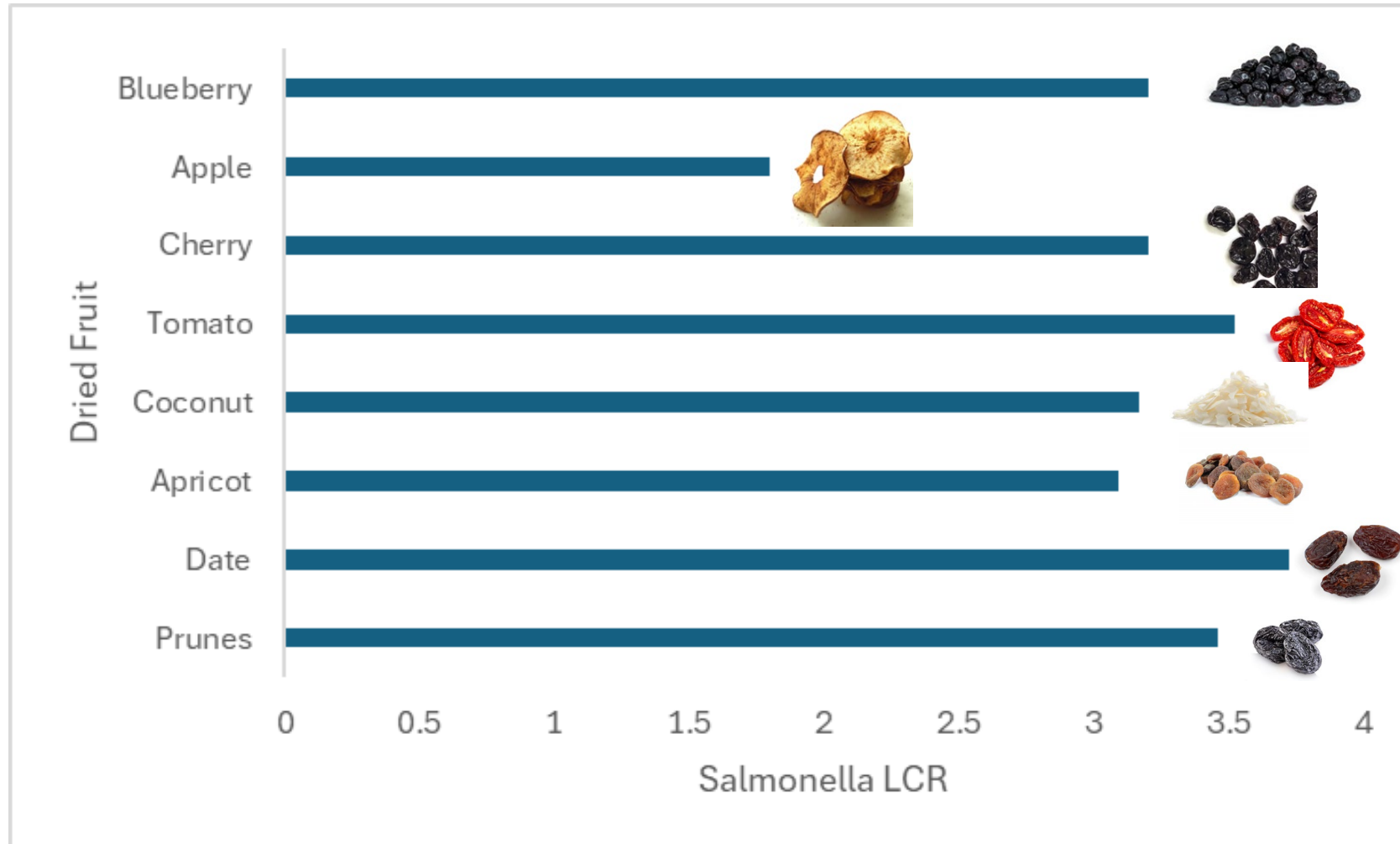
Commercial Hydroxyl-Radical Process Reactors



Low Moisture Foods



Hydroxyl Radical Process: Dried Fruit



CANADA

Year-long salmonella outbreak from imported pistachios 'difficult to control.' Here's why



By **Sean Previl** • Global News

Posted April 15, 2026 2:55 pm · Updated April 15, 2026 3:55 pm · 3 min read

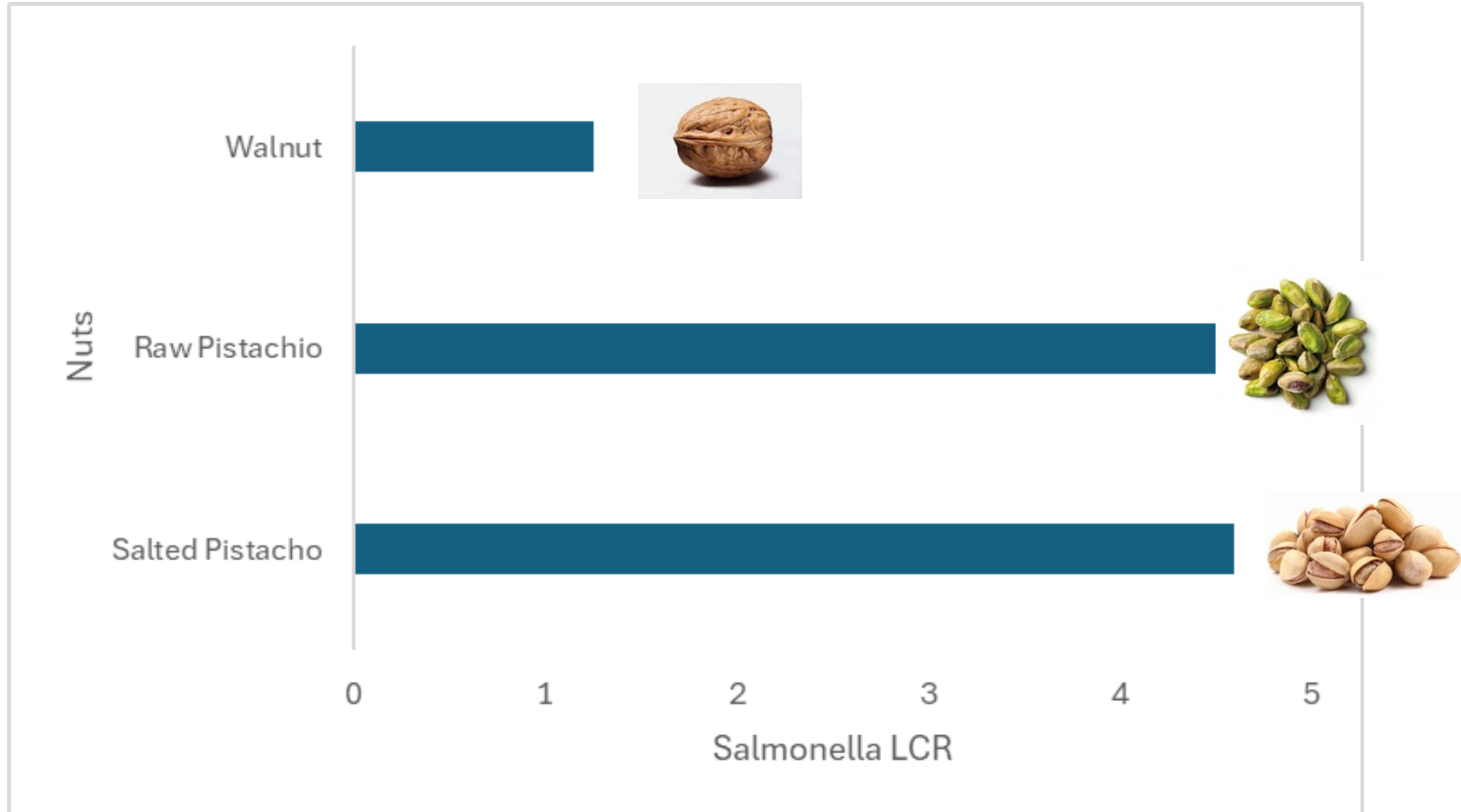
Canada pistachio-linked salmonella outbreak still ongoing more than a y...
A salmonella outbreak linked to pistachios sold in Canada is still ongoing more than a year after the first...



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Hydroxyl Radical Process: Nuts

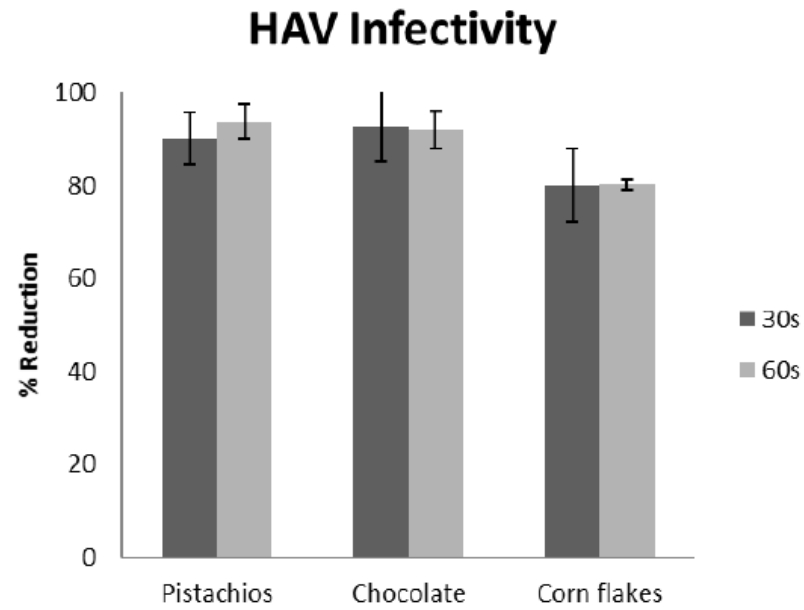


- Food safety of low moisture foods
- Dr Neda Nasheri (Health Canada)
- Inactivation of feline calicivirus (norovirus) and hepatitis A
- Dried nuts, chocolate, cornflakes

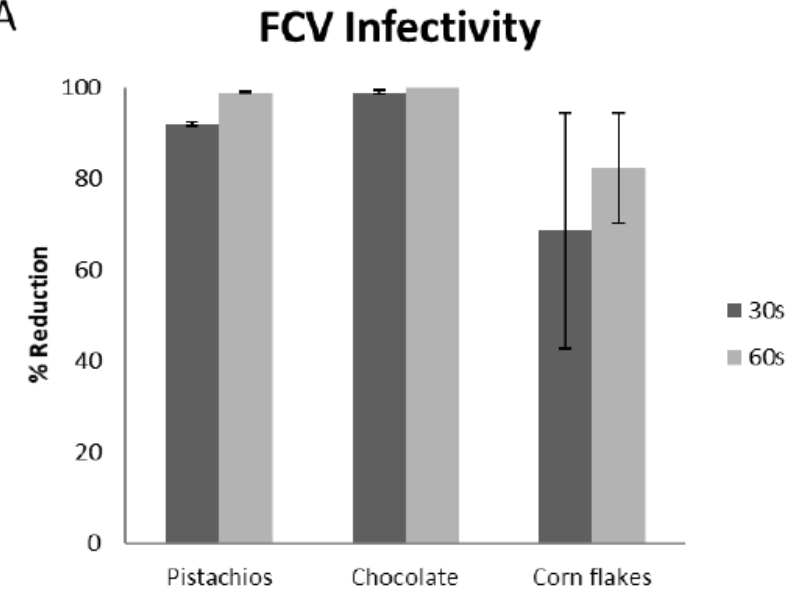


Infectivity Assay

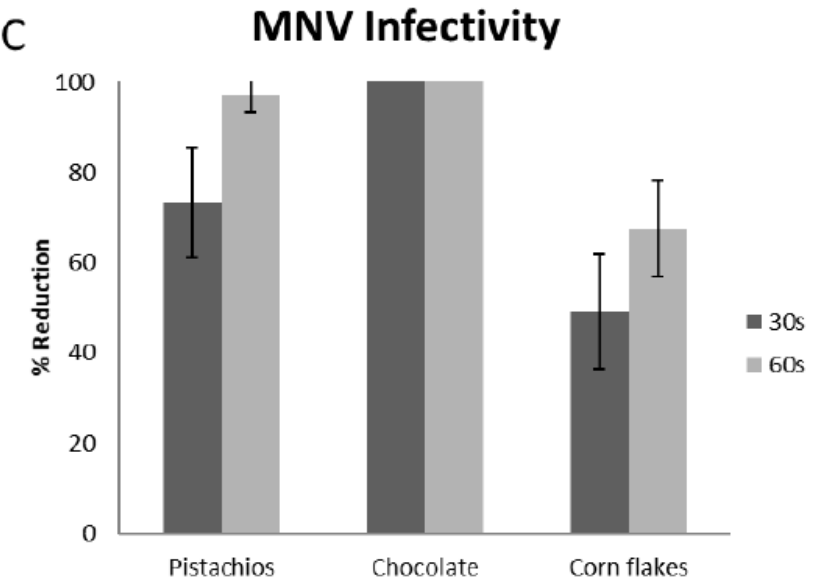
E



A



C



Kibble

Operating parameters

3% hydrogen peroxide

30 ml/min

UV-C 226 mJ/cm²

30s treatment time

Salmonella: 1.04 LCR

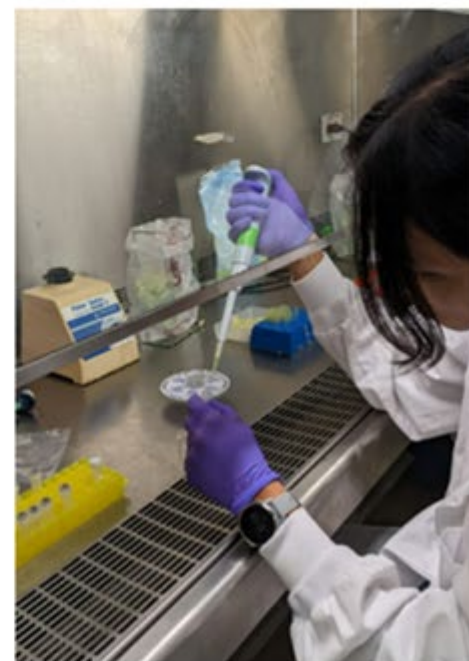
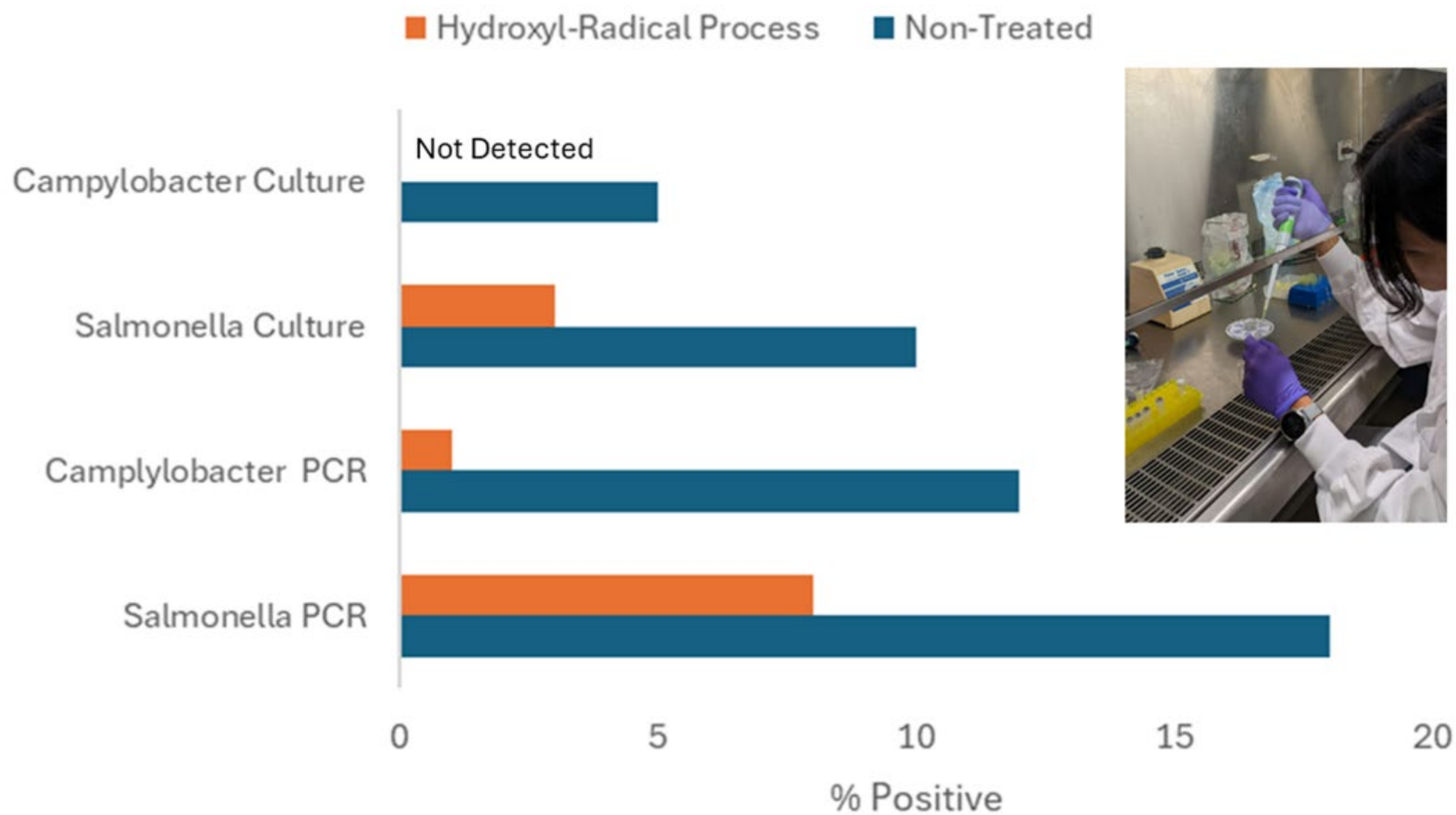




Meat, Fish and Eggs

Poultry Meat

- Standards for Poultry Parts
 - *Salmonella* 15.4% (USDA-FSIS) 18.2% (CFIA)
 - *Campylobacter* 7.7% (USDA-FSIS) 25.2% (CFIA)
- Verification testing
- *Salmonella* <8/52 (USDA-FSIS) <9/52 (CFIA)
- *Campylobacter* <4/52 (USDA-FSIS) <13/52 (CFIA)



Quality Metrics

Parameter	Control	Hydroxyl-Radical
% Cook Loss	11.49±1.8a	11.09±2.64a
% Drip Loss	0.37±0.23a	0.27±0.32a
Whiteness	61.64±2.61a	58.7±2.46a
Firmness	0.41±0.11a	0.46±0.11a

Smoke Salmon

Balance between lethality and preserving color

Optimised treatment

105 ppm Electrolyzed water

pH 4

110 mJ/cm² UV-C dose

Listeria monocytogenes: 1.75± 0.39 log CFU Reduction



Before



After AOP treatment



Table Eggs

RECALL

Egg recall linked to salmonella outbreak in 9 states that's left dozens ill: Avoid these 2 brands

The recall affects eggs sold in three states.

CANADA: KTHX

These 4 egg brands have been recalled due to salmonella



An egg brand has been found to be unsafe, (Government of Canada)



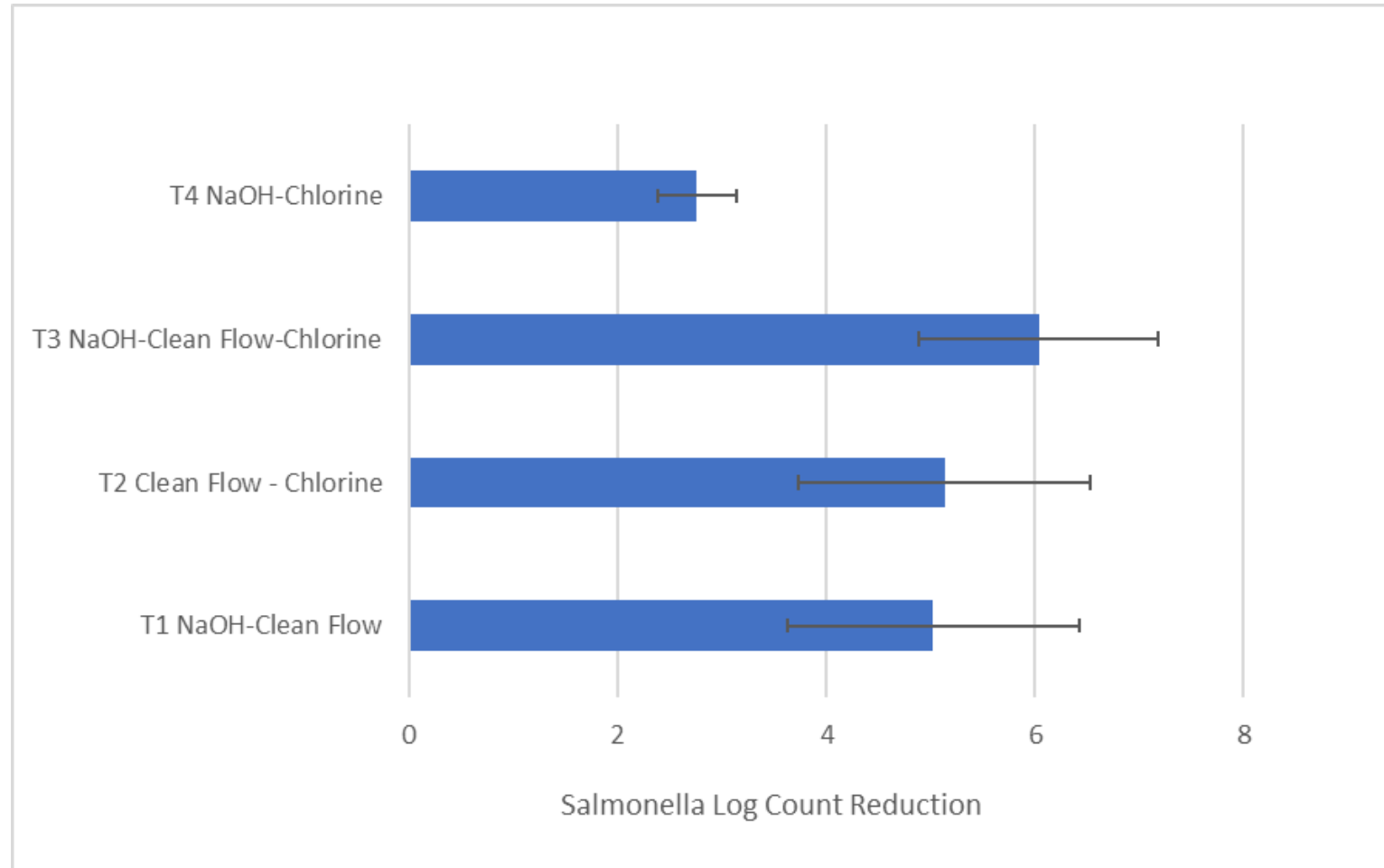
**EGGS RECALLED IN ILLINOIS AND 8 OTHER STATES
DUE TO SALMONELLA**

Table Eggs

- Washing eggs is mandatory
- Current method
 - Warm chlorinated water
 - NaOH rinse
- No negative effects on egg shelf-life



Combining Hydroxyl-Radical Process with Washing (chlorinated sodium hydroxide)



Trays

- Additional application
- Egg trays
- Chick transport



- *Salmonella*: 6.98-7.47 log cfu/inoculation area
- No *Salmonella* recovered post-treatment



Knife disinfection



Inoculation



Clean Flow



Clean Flow



Recovery

Log Count Reduction *E. coli* = 5.11

A large industrial freezer, likely a blast freezer, is shown. The interior is filled with a thick layer of frozen green peas. The freezer has a large, open front door, and the peas are piled up to the top of the visible area. The background shows the industrial structure of the freezer, including metal frames and pipes.

Frozen Foods

Public Health Notice: Outbreak of *Salmonella* infections linked to frozen whole kernel corn



March 11, 2022: Final Update

This notice has been updated to reflect that the outbreak appears to be over and the outbreak investigation has been closed.

Health Canada recalls frozen fruit due to norovirus concerns: 'Do not consume'

The Canadian Food Inspection Agency has issued a recall for two kinds of Alasko-brand frozen fruit due to possible norovirus contamination.

Yahoo Canada Lifestyle Editors
Tue, June 13, 2023 at 9:47 a.m. EDT
7 min read

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Frozen blueberries sold in Canada and U.S. recalled over listeria contamination risk, FDA says



Publix frozen berries recall expands over E. coli outbreak linked to 12 illnesses

By Top Class Actions | August 31, 2026

Category: [Legal News](#)

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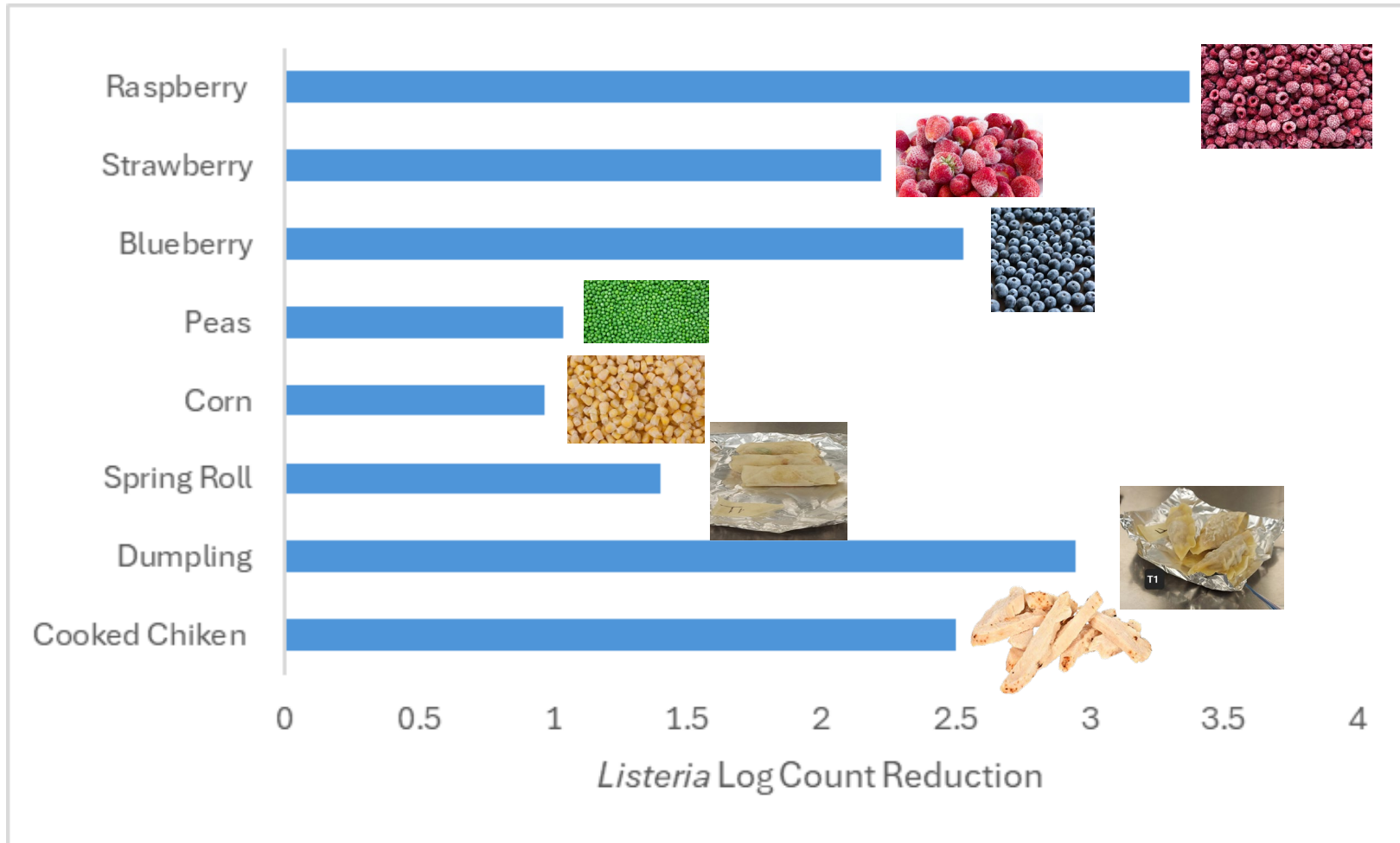
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Frozen Foods



Frozen Vegetables



Treatment	<i>Listeria</i> Positive	<i>Listeria</i> Negative
Before Hydroxyl Radical Process	5	41
Post Hydroxyl Radical Process	0	52

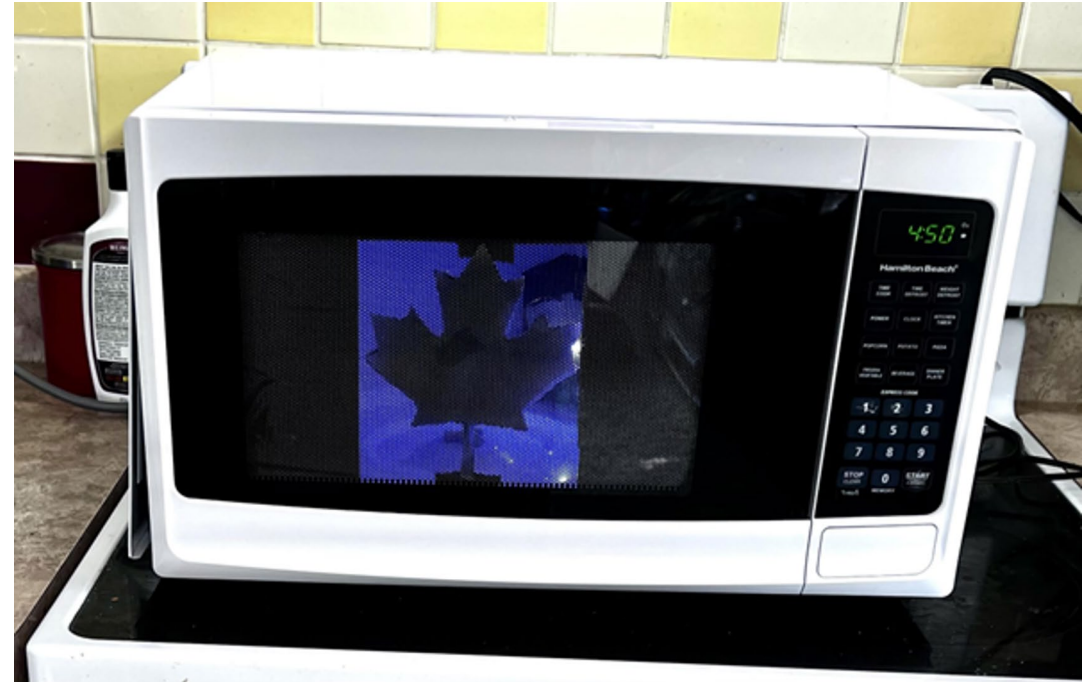
Future Developments

Domestic Unit

- UV-LED – H_2O_2
- Microwave UV- H_2O_2
- Food decontamination
- Toys/electronics/containers
- Shelf-life extension
- Decontamination of refrigerators

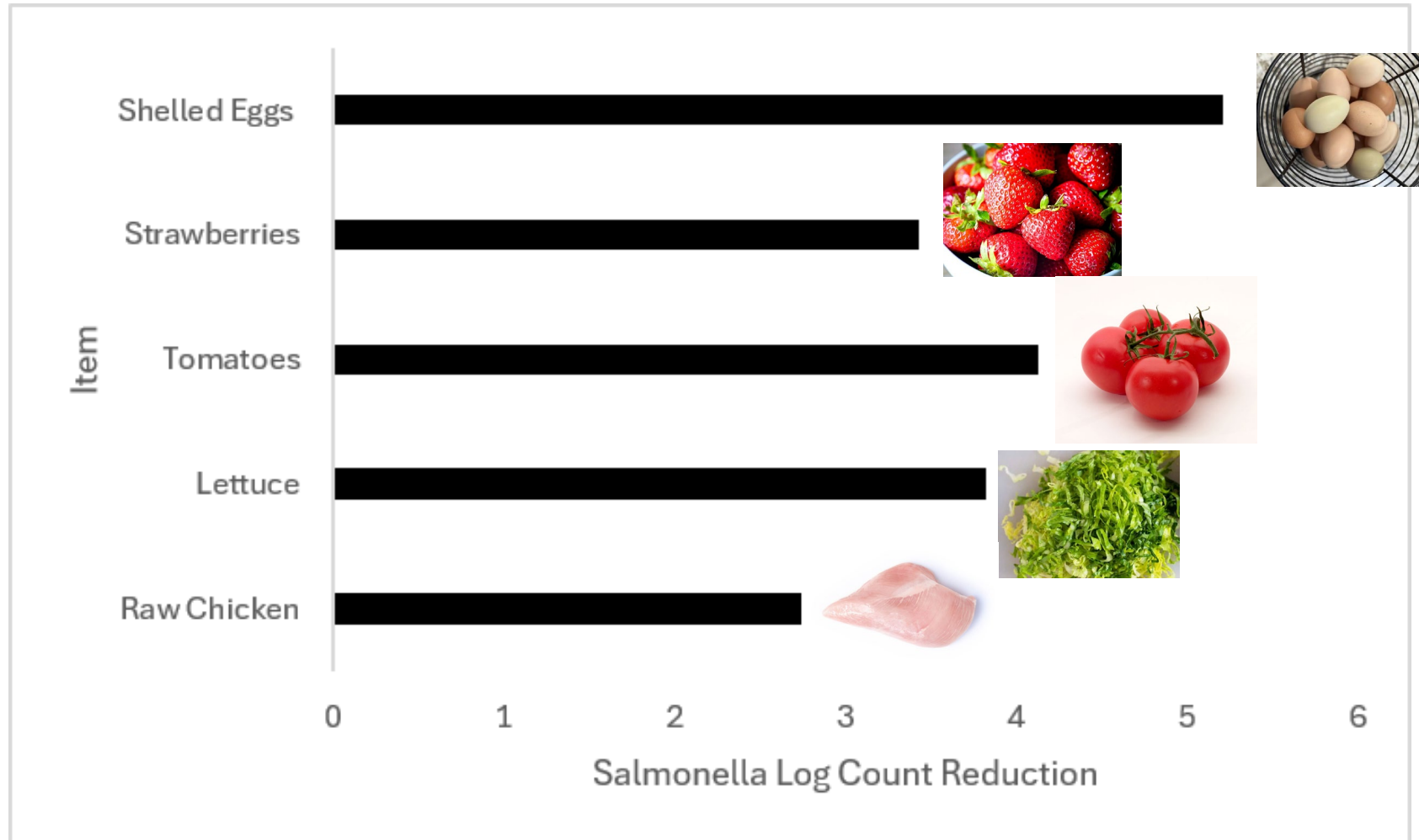


Domestic Unit



<https://youtu.be/OFsILnvueWw>

UV LED (265 nm):Hydrogen Peroxide (3% v/v)



Biofilms

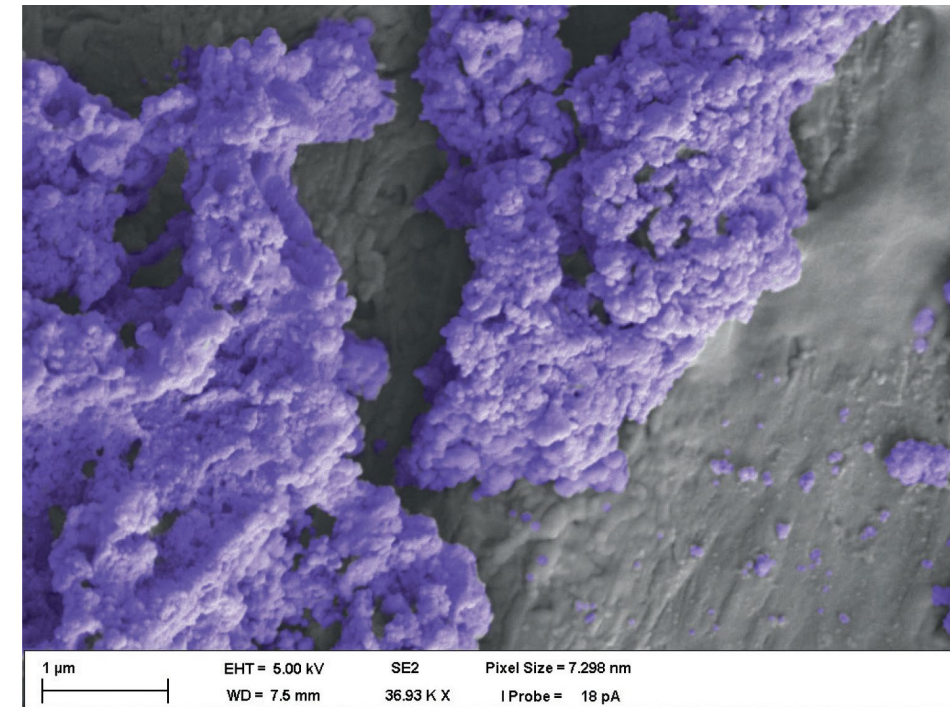
- Collection of microbes held in a exopolysaccharide matrix
- Homogenous: Single microbial type
- Heterogenous: Multiple species
- Continuous source of contamination

Dry biofilms

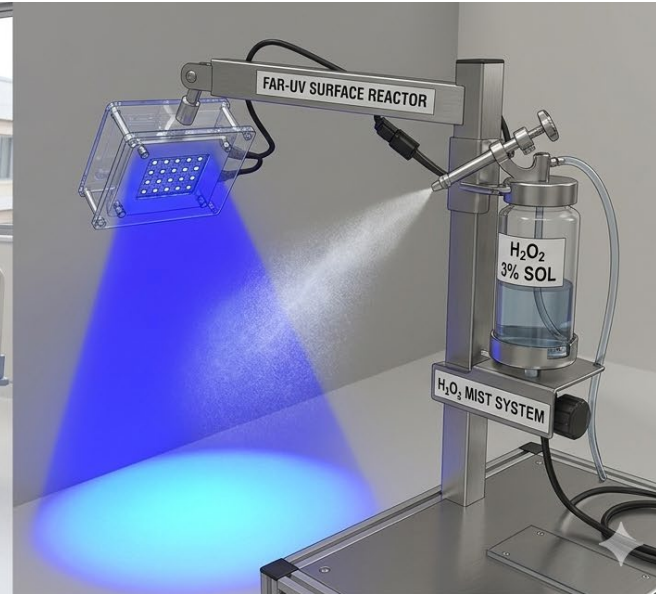
- First reports: 2012 in Australian ICU
- Significant in LMF and clinical environments

Dry Biofilms

- Formed by wet and dry cycling
 - High relative humidity environments
 - Heterogeneous biofilms (cooperative)
 - Thin layer dried on cells
 - High sanitizer resistant
 - Extended persistence (>10 years)
-
- Not removed by swabbing
 - Return low ATP results
 - Detection and control of dry biofilms is an active area of research



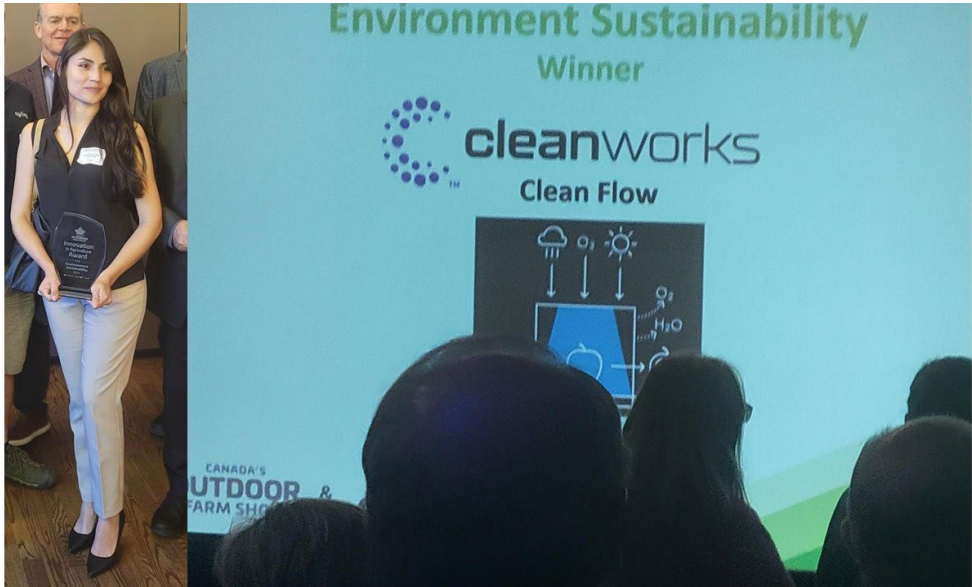
Hydroxyl-radical process in surface and area sanitation



Transporter Sanitizer



Awards and Recognitions





Research Team

- Dr Mahdiyeh Hasani
- Dr Cristina Chiappe
- Amanda VanderVeen
- Vanessa Camacho
- Sapphire Aberdeen
- Aelle Viandier-Delaunay
- Nathalie Sanchez
- Lara Warriner

