Validation of UV Treatments for Decontaminating Fresh Produce

Keith Warriner

kwarrine@uoguelph.ca

Center for Public Health and Zoonosis (CPHAZ)

Department of Food Science

FSMA Final Rule Fresh Produce

Part 6

- Measures to be taken to avoid cross-contamination between produce
- Handling produce to prevent contamination with know or reasonable foreseeable hazards
- Packaging that is fit for intended use and unlikely to support the growth or transfer of bacteria.

FSMA Final Rule for Preventive Controls for Human Food (excludes farms)

FDA Food Safety Modernization Act (FSMA), established in section 418 of the Federal Food, Drug, and Cosmetic Act (FD&C Act) (21 CFR)

- Food Safety Plan
  - Hazard Analysis
  - Prevention controls
    - Written
    - Validated (minimum and maximum values)
    - Monitored (as appropriate)
    - Corrective action
    - Verification (whole chain grower – retailer)

    Descriptive rather the prescriptive

Fresh Produce Market

- Ready-to-eat Salads Market Growing at 10% per Year
- Current Market Value >US$70bn
- Greater Diversity of Produce Available (All Year Round)
- Centralized Production

The Fresh Produce Problem

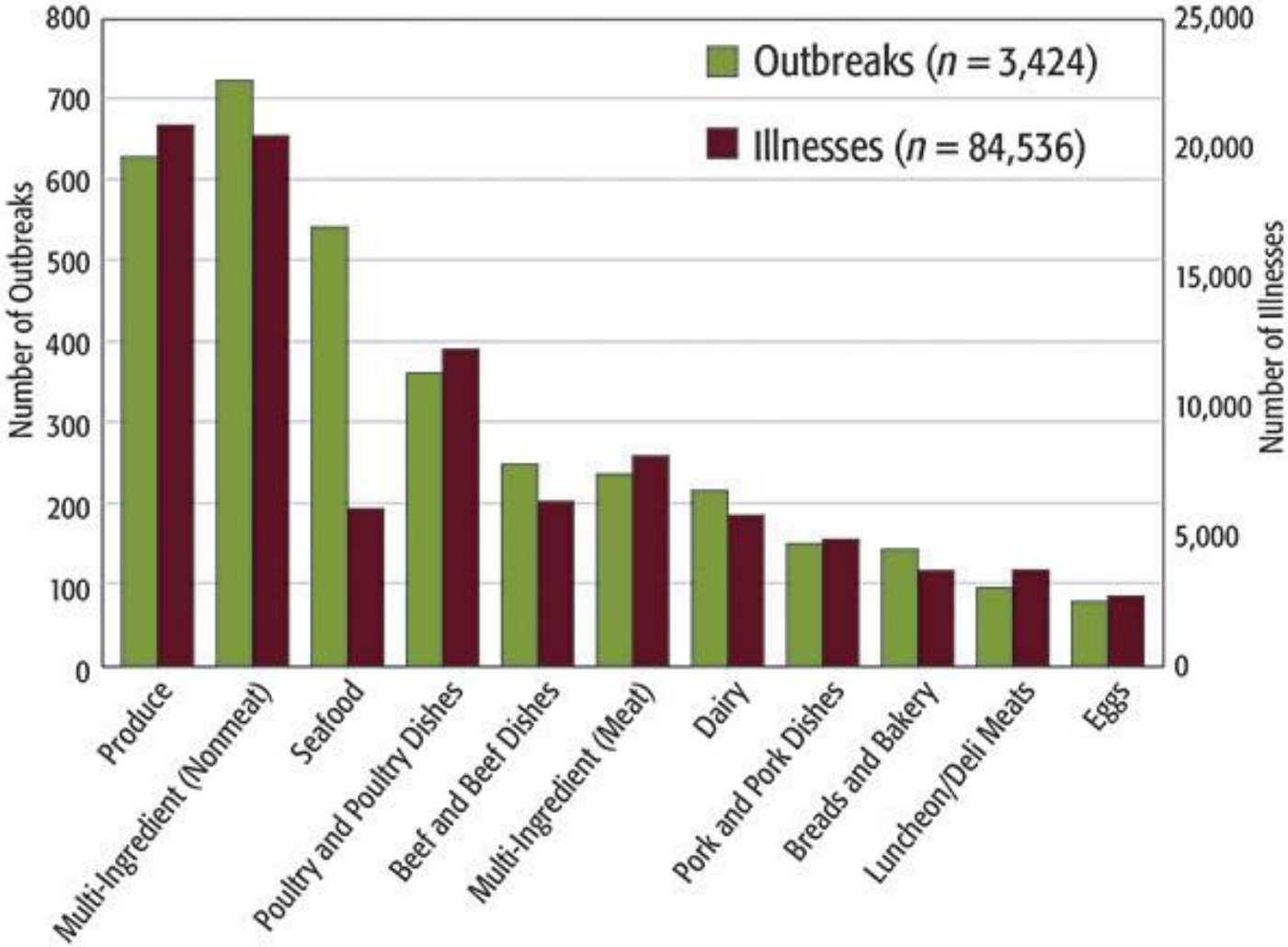
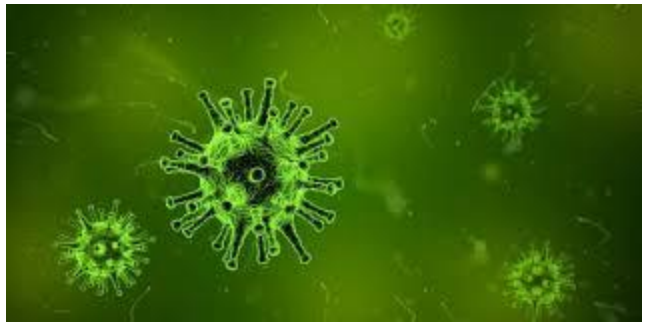
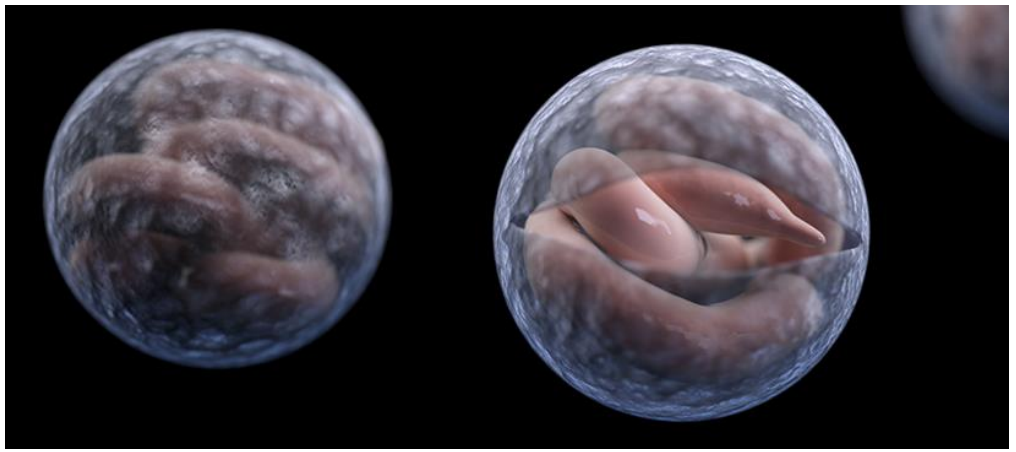


Figure 1. Outbreaks and Illnesses Due to Food, 2004–2013[1]

Pathogens of Concern

- Shiga Toxin producing *Escherichia coli*
- *Salmonella*
- *Listeria monocytogenes*
- Norovirus
- *Cryptosporidium*

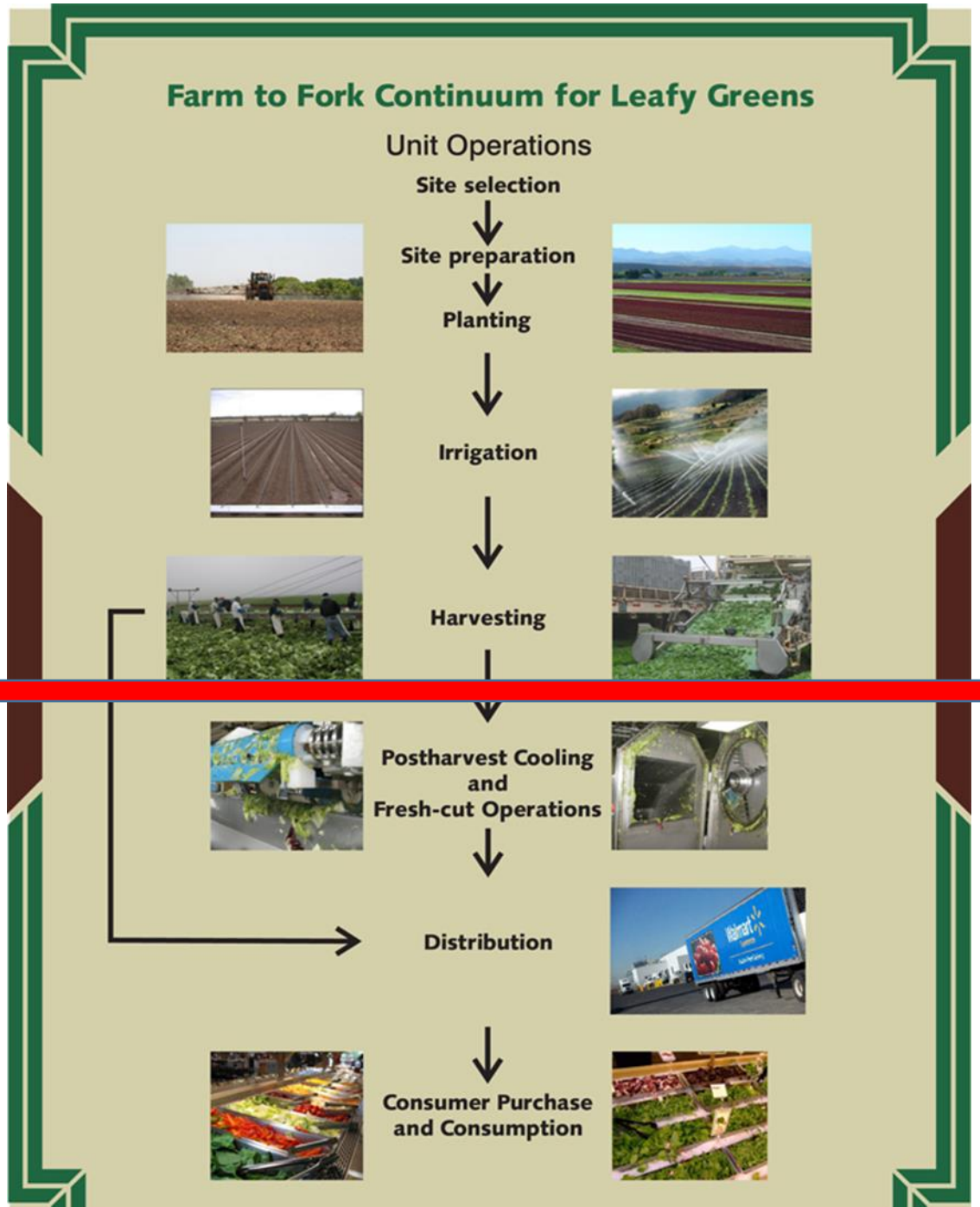




Escherichia coli (STEC)
Listeria monocytogenes
Salmonella

Norovirus
Hepatitis A

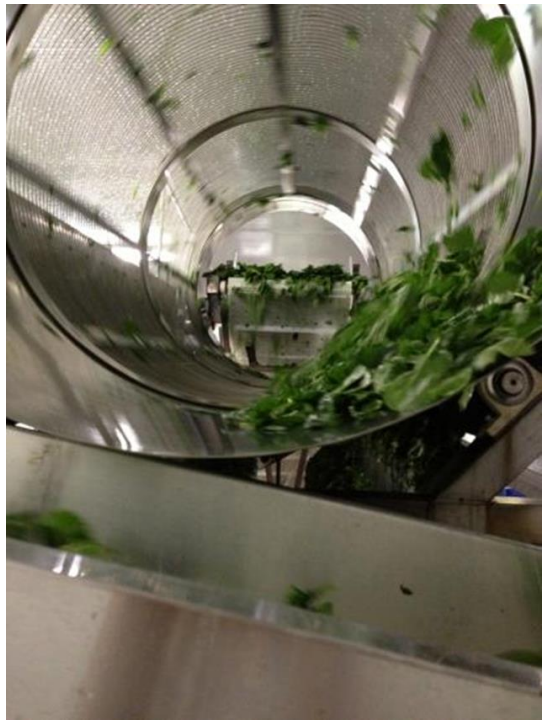
Cyclospora
Cryptosporidium



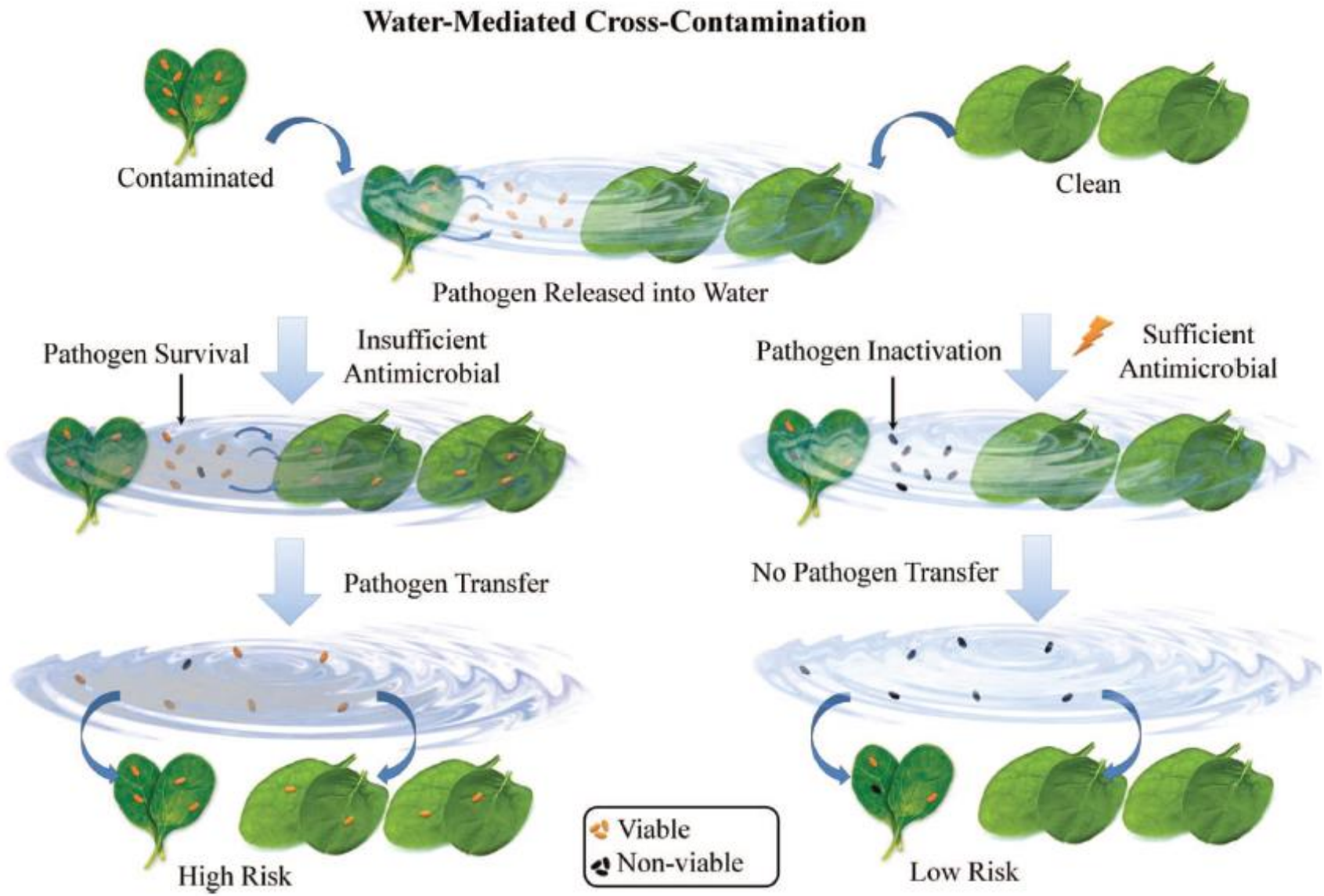
Good Agriculture Practice
GAP

Post-Harvest Wash
Sanitation

Temperature Control



Cross-contamination during washing?



What level of pathogen inactivation and at what rate?

Current View on Post-harvest wash

- Limited efficacy
- Aim to prevent cross-contamination
- Maintaining free chlorine (sanitizer) concentration
- Validation is identifying the sanitizer, concentration and contact time to inactivate pathogens in wash water

Validation

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General Interest

Guidelines To Validate Control of Cross-Contamination during Washing of Fresh-Cut Leafy Vegetables

D. GOMBAS,[1] Y. LUO,[2] J. BRENNAN,[3] G. SHERGILL,[4]† R. PETRAN,[5] R. WALSH,[5] H. HAU,[5] K. KHURANA,[6]‡
B. ZOMORODI,[7] J. ROSEN,[8] R. VARLEY,[9] AND K. DENG[10]*

Government, Academia and Industry

Wash Water Validation Group

- Series of meeting and teleconferences
- Factors to consider in validation of wash process
- Too many Chefs
- Industry standard

ACKNOWLEDGMENTS

This article has been written as a result of discussions of the Wash Water Validation Group, composed of contributors from industry, academia, and government. The authors thank the other members of the Wash Water Validation Group for their expertise and discussions, which were essential to developing the technical concepts in the paper: Joe Holt (Earthbound Farms), James Gorny (Produce Marketing Association), Steven Lange (Ecolab), Tony Banegas (Ready Pac), John Gurrisi and Courtney Parker (Chiquita Brands), Loys Larpin (Aqua Pulse Systems), Felice Arboisiere (Yum Brands), Robert Brackett (Illinois Institute of Technology), Trevor Suslow (University of California–Davis), Keith Warriner (University of Guelph), Keith Schneider (University of Florida), Vincent Hill (Centers for Disease Control and Prevention), Tong-Jen Fu, Crystal McKenna, David Ingram, John Larkin, Mickey Parish, and Mary Lou Tortorello (U.S. Food and Drug Administration). The Wash Water Validation Group thanks the following persons for reviewing the manuscript prior to submitting it for publication: Devon Zagory (Zagory and Associates), Glenn Black (U.S. Food and Drug Administration), Ginger Povenmire and Micah Fuson (Apio), Ronald Wesley and James Zeigler (Ready Pac). The authors thank Sam Van Haute and Imca Sampers (University of Gent) and Ana Allende and Mabel Gil (CEBAS-CSIC) for

Options for Validation

- Option 1: Prevent cross-contamination under worst-case scenario using a surrogate.
- Option 2: Determine minimal sanitizer concentration under worse case scenario
- Option 3: Maintain minimum sanitizer concentration irrespective of worse case scenario

Options 1

1. Surrogate selection
2. Inoculation of high volumes of produce
3. Be able to identify inoculated vs non-inoculated (redleaf vs iceberg)
4. Run tanks with no or little sanitizer (Positive control)
5. Run tanks with antimicrobial levels to prevent cross-contamination

Outcome: No recovery of surrogate on non-inoculated produce

Problems with Option 1

- No surrogates currently available or agreed upon
- Inoculation of large batches of product
- Disposal of product after trials
- Expensive (3 repeats per condition)
- Detection of surrogate (how sensitive)?
- Challenging to designate worse case scenario
- Sanitizer concentration and organic loading would be moving target

Option 2: Antimicrobial Sensor Validation

- Sensor detects antimicrobial levels under worse case scenario

1. Determine minimal free chlorine level to achieve target inactivation
2. Position sensors at different locations within the tank and measure free chlorine (under worse case scenario-high organic loading)
3. Increase chlorine feed rate until achieves minimum to be lethal to target

Outcome: Identify antimicrobial feed rate to achieve inactivation of target

Limitations of Option 2

- Identification of minimal chlorine concentration
- To achieve what log reduction?
- Defining the worse case scenario
- Over-dosing of chlorine in tanks (health, safety and cost)
- Disinfection byproducts are antimicrobial

Option 3

- Same as Option 2 but place sensor at cold point (i.e. lowest free chlorine concentration in tank) – Chlorine mapping

- Independent of worse case scenario

- Very similar to current systems based on ORP.

Limitation: Does a cold point exist? Shift depending on reactivity with chlorine.

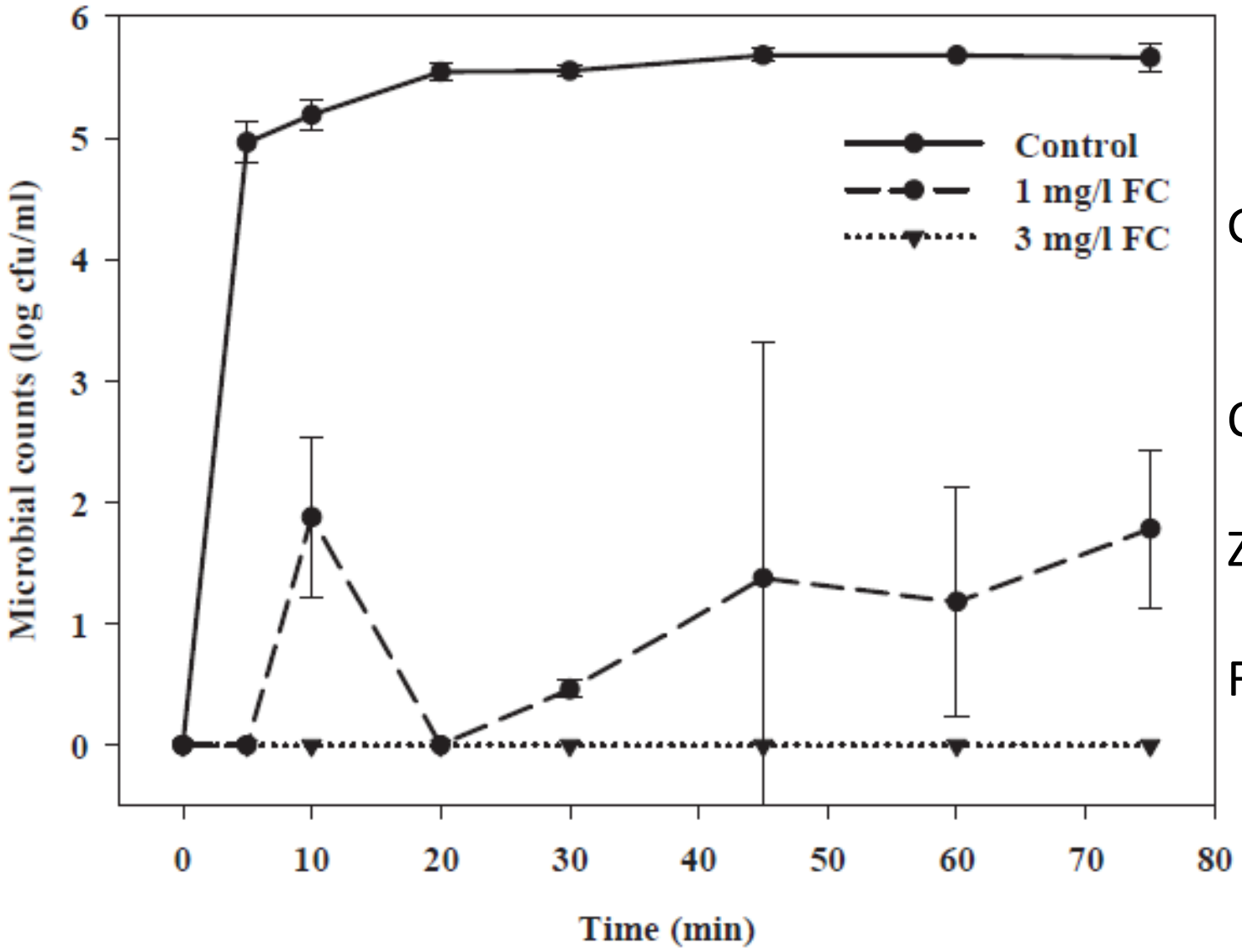


Fig. 5. Changes in *E. coli* O157:H7 populations during disinfection of process wash water by different free chlorine (FC) concentrations under increasing chemical oxygen demand. Results are means of at least two repetitions ± standard deviation.

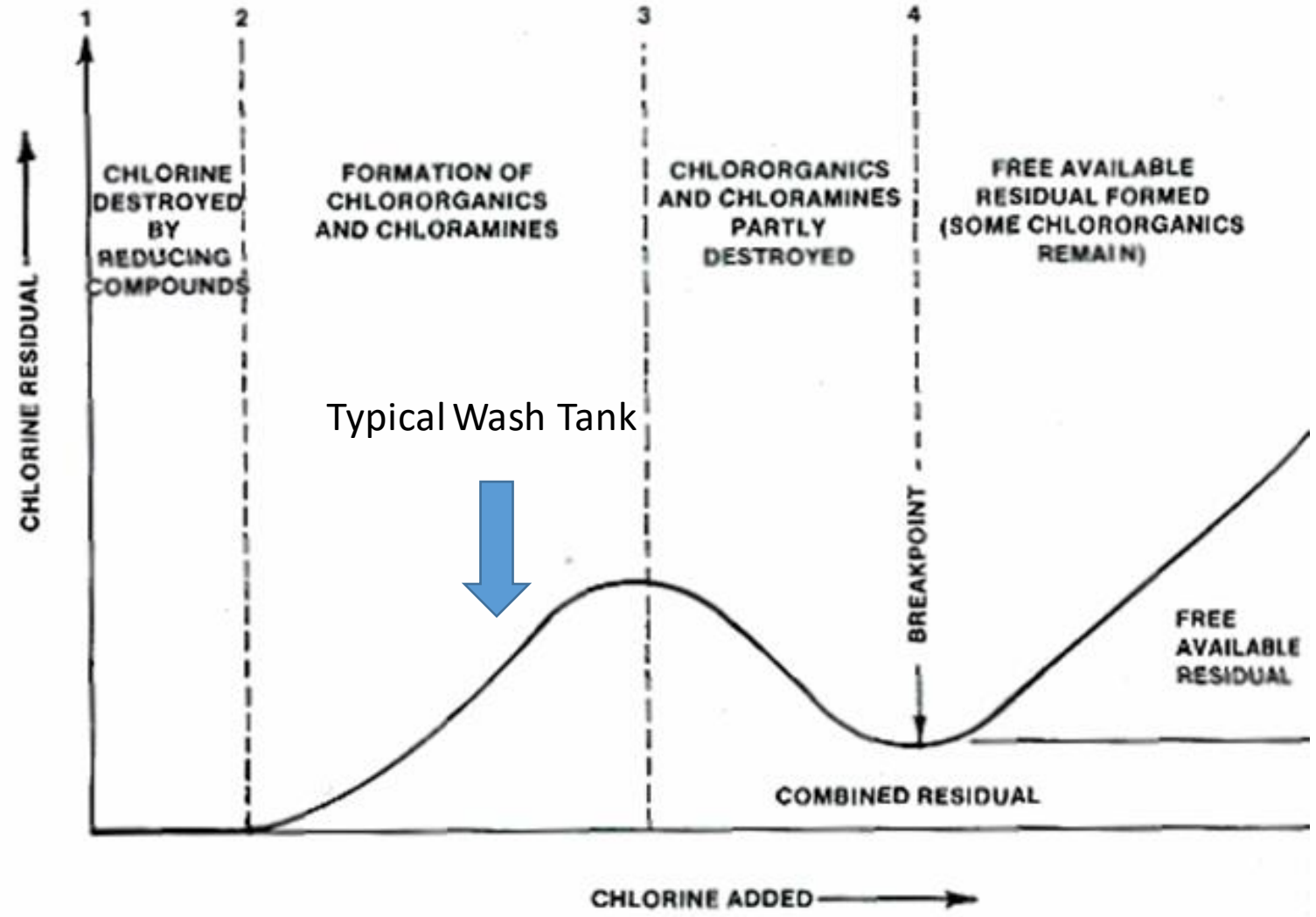
Gomez-Lopez et al 2014

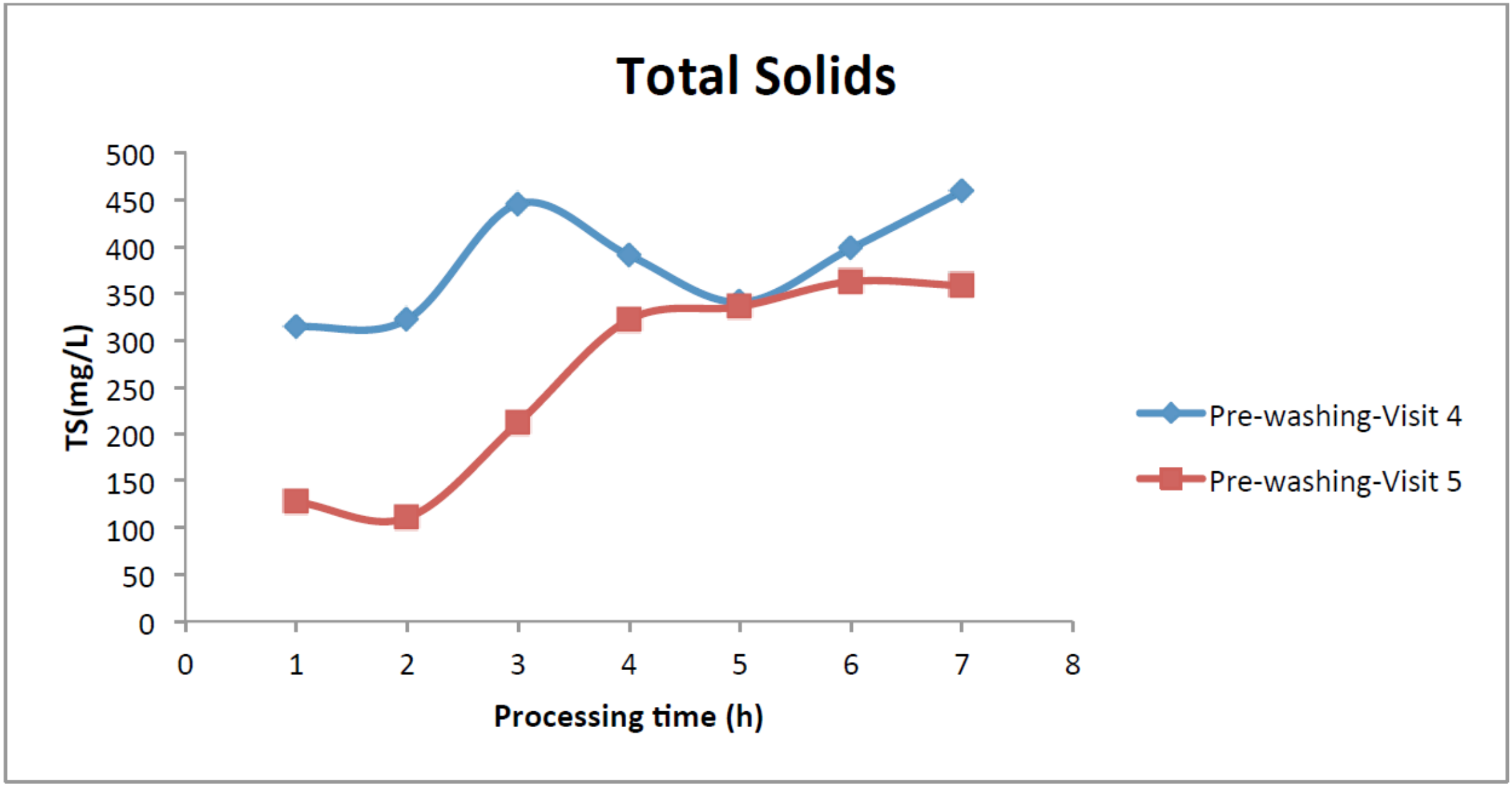
Conclusion: 7 ppm Free Chlorine

Zhou et al 2015 : 4 ppm Free Chlorine

FDA: 10 ppm Free Chlorine

Maintaining Free-Chlorine Concentration is a Challenge

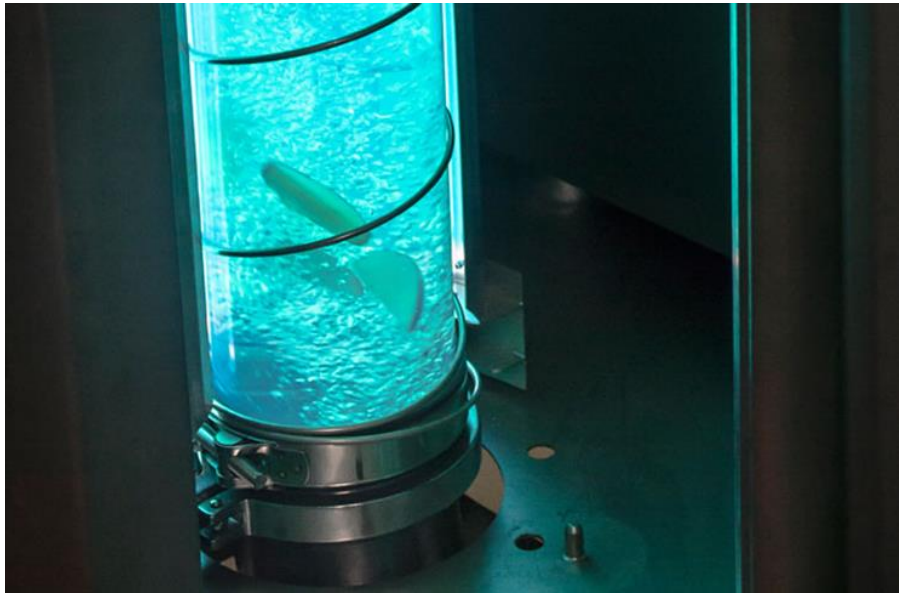


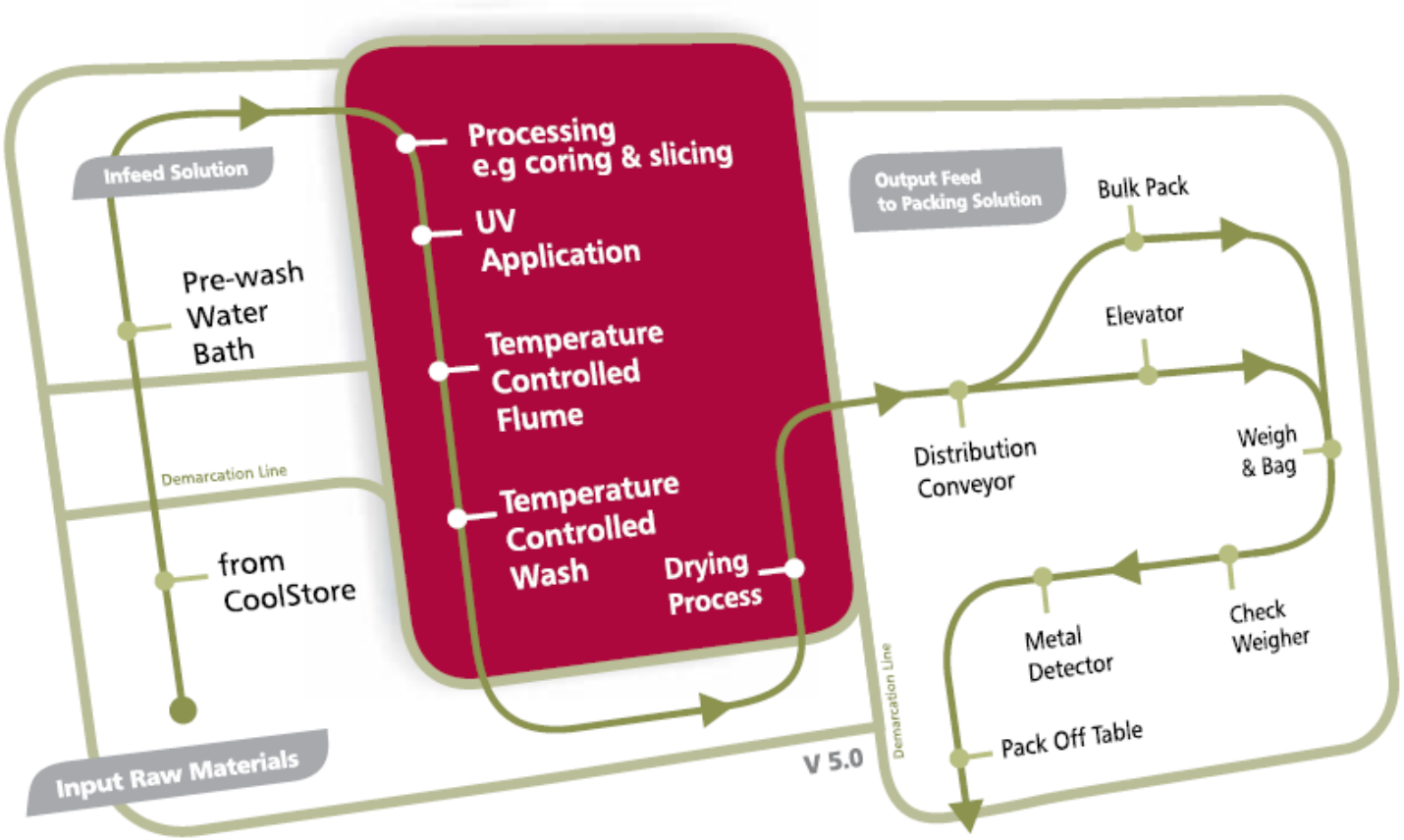

Total Solids
TS(mg/L)
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
Processing time (h)
Pre-washing-Visit 4
Pre-washing-Visit 5

How Can UV be Applied?

- Continuous decontamination of water
  - Within or external to wash tanks
- Reduce chlorine demand
  - Water treatment and recycling
- Alternative intervention step
  - Stand alone treatment

Water Assisted – UV Treatment





Fresh Appeal

Water: 50°C Combined with UV

UV treatment of water

- Challenges
- Turbidity
- High UV absorbing
- Sanitizer compatibility

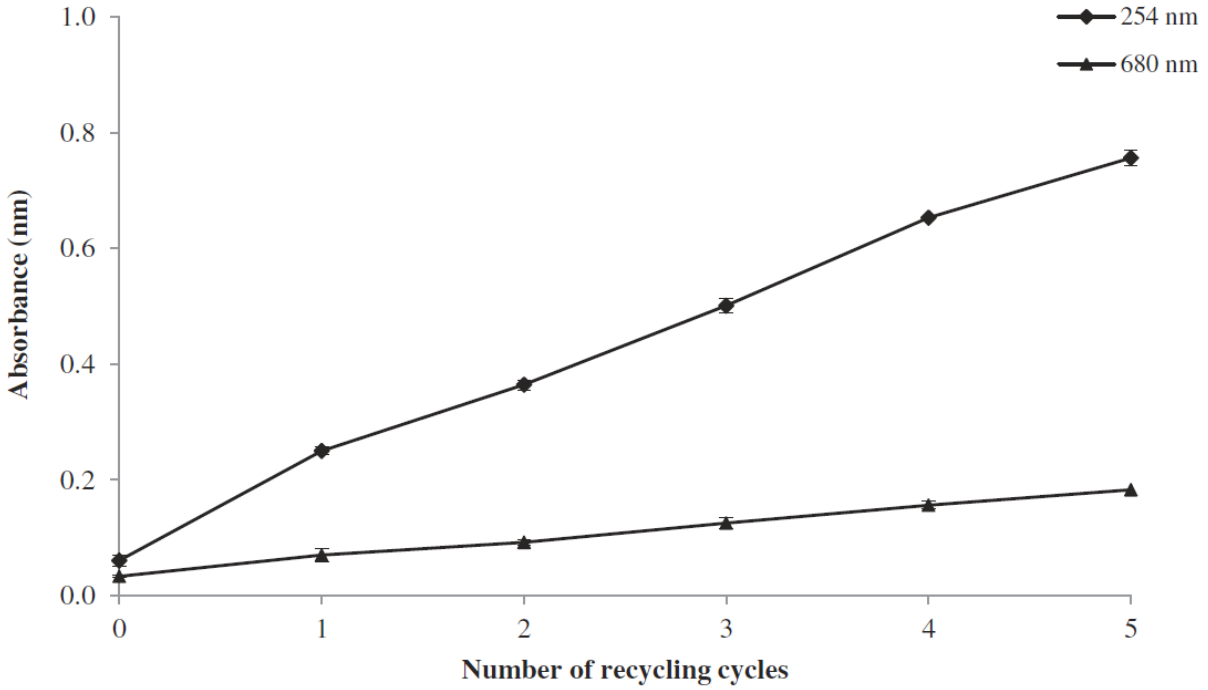


Fig. 1. Absorbance at 254 and 680 nm of wash water obtained by increasing washing cycles of fresh-cut lamb's lettuce.

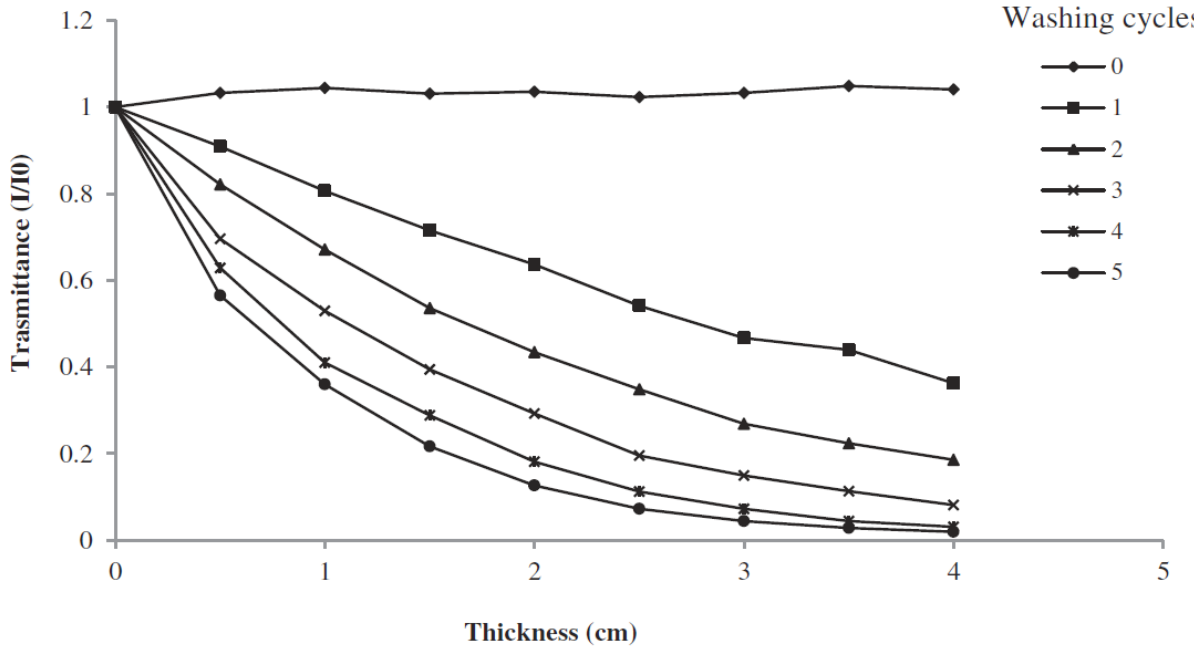


Fig. 2. Transmittance of UV-C light at increasing depth in wash water obtained by increasing washing cycles of fresh-cut lamb's lettuce.

Ignat et al., 2012

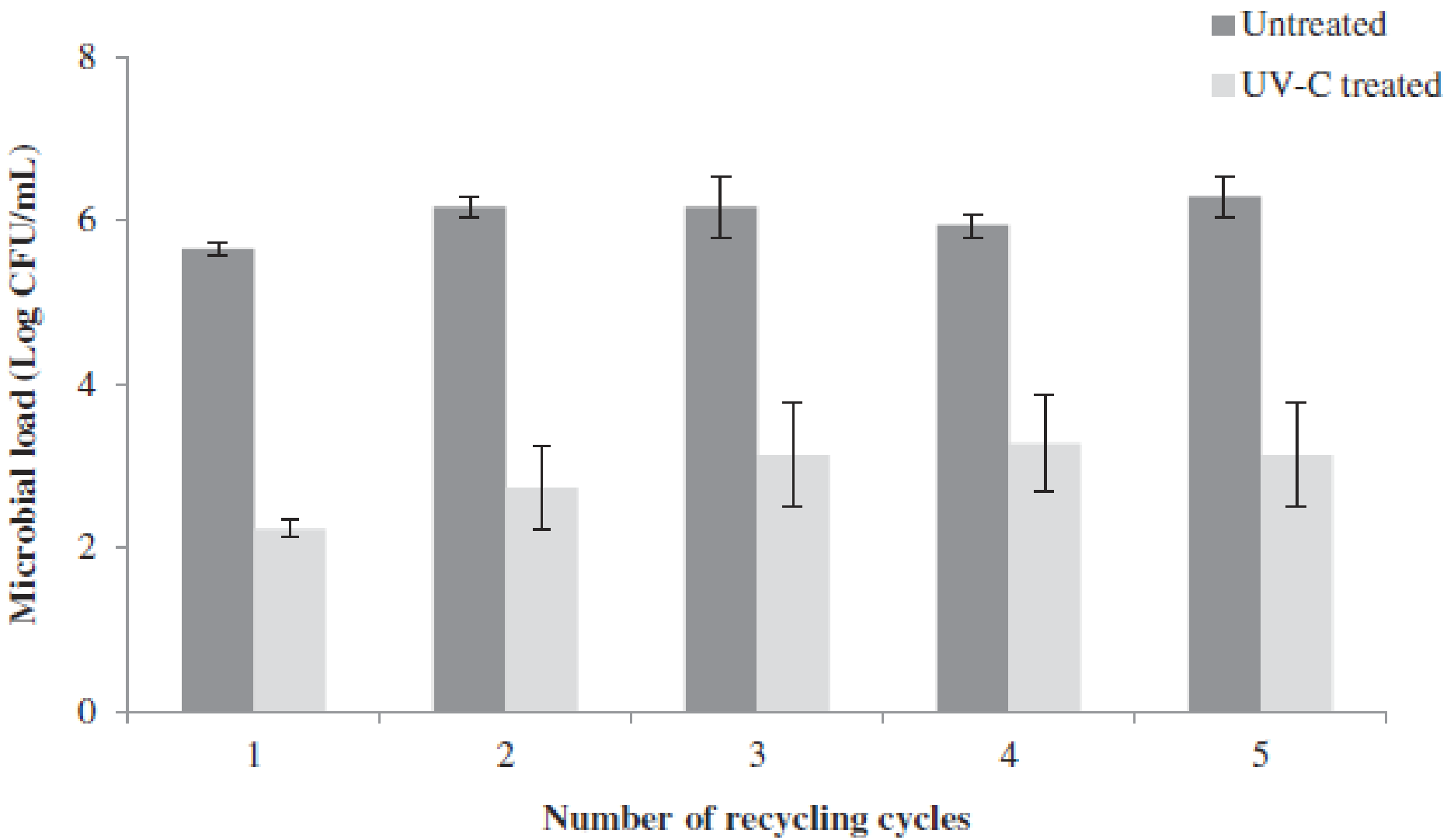
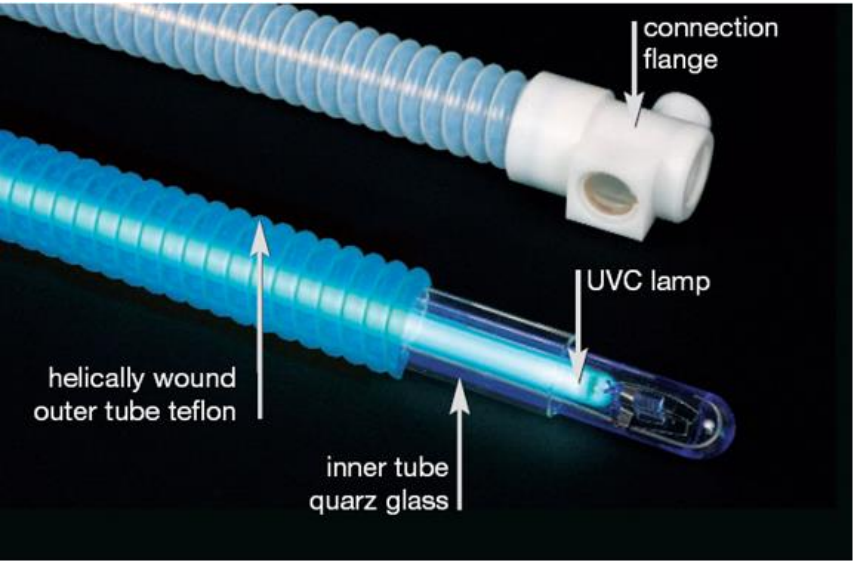
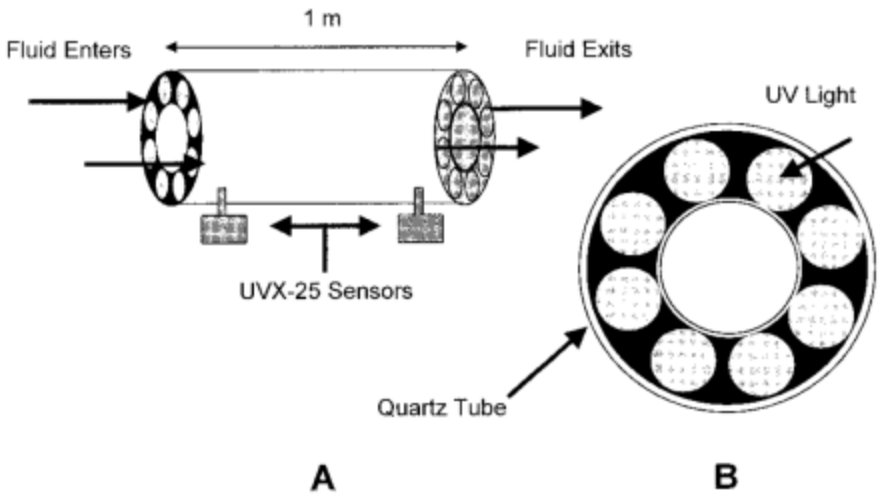


Fig. 3. Total viable counts in wash water obtained by increasing washing cycles of fresh-cut lamb's lettuce and exposed to 0.4 kJ/m^2 UV-C light.

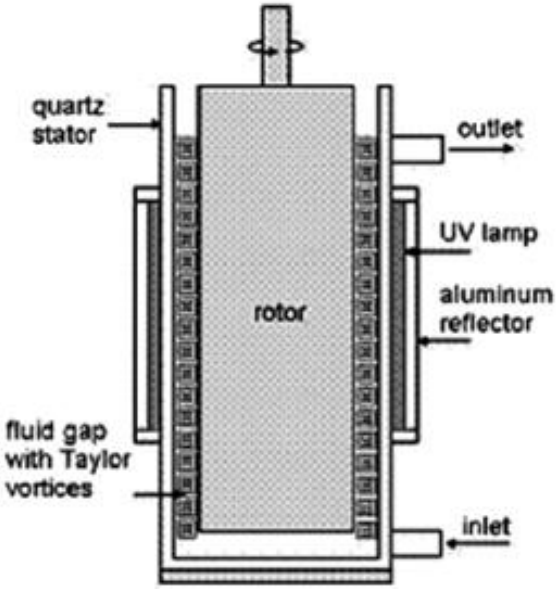
UV Reactors for Low UV Transmission Liquids



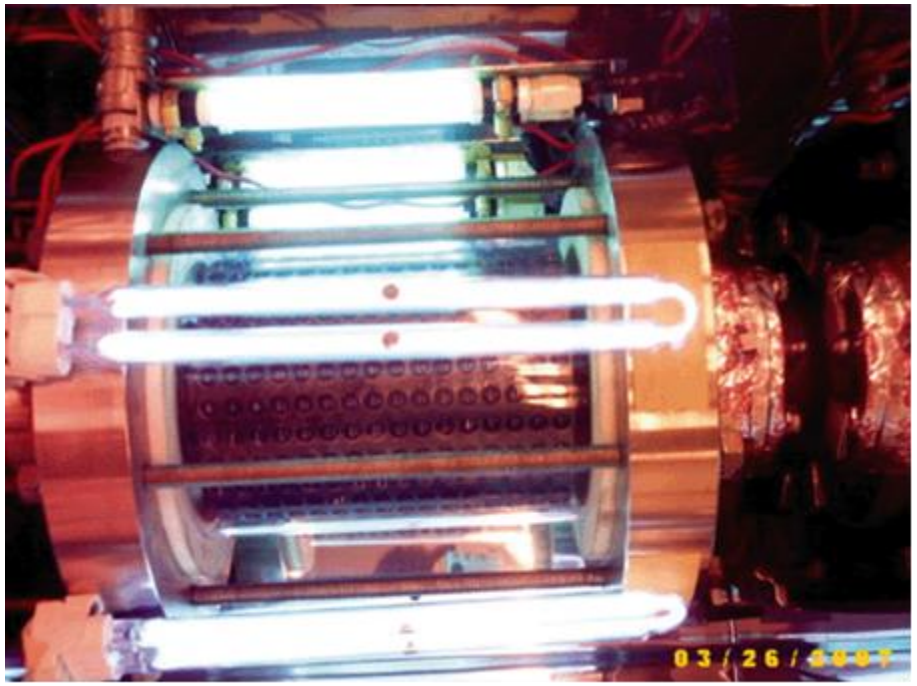
Dean Flow



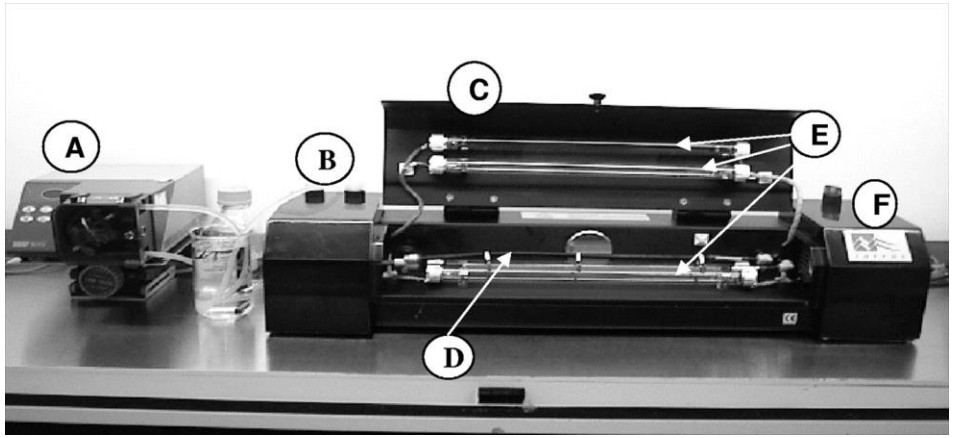
Flow Through Reactor



Taylor Couette Reactor



Shockwave Reactor

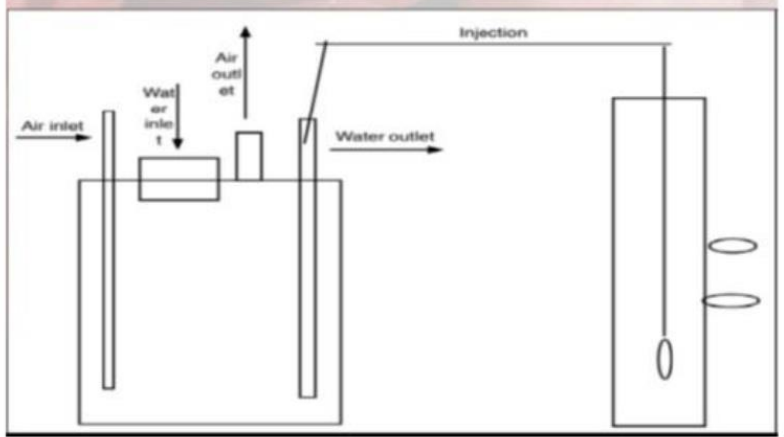


Static Mixer

Thin Film Reactor

Water Treatment and Recycling

Dissolved Air Floatation Reactor

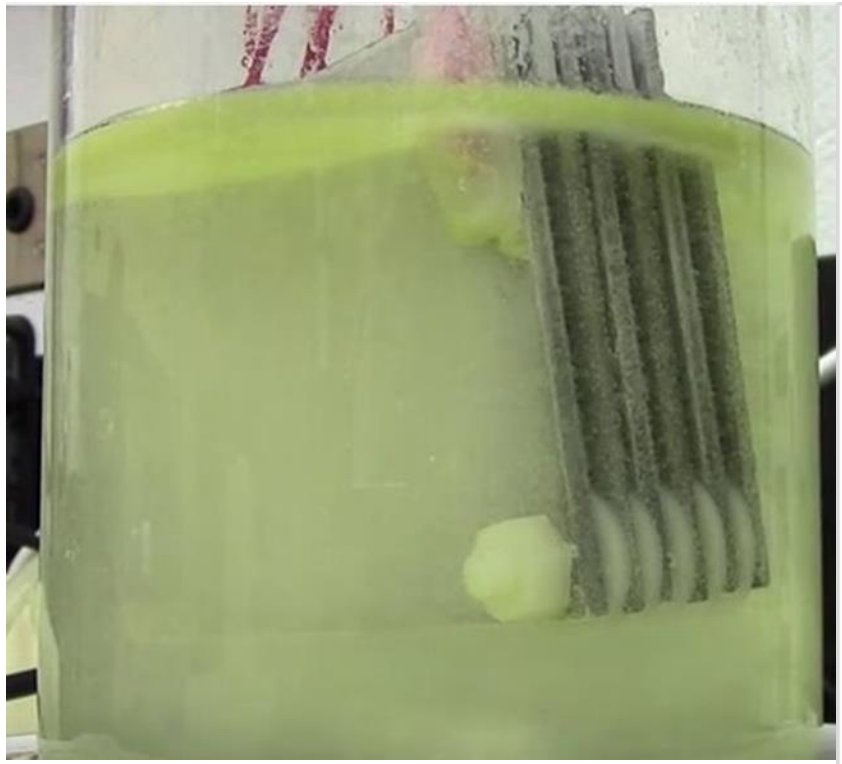


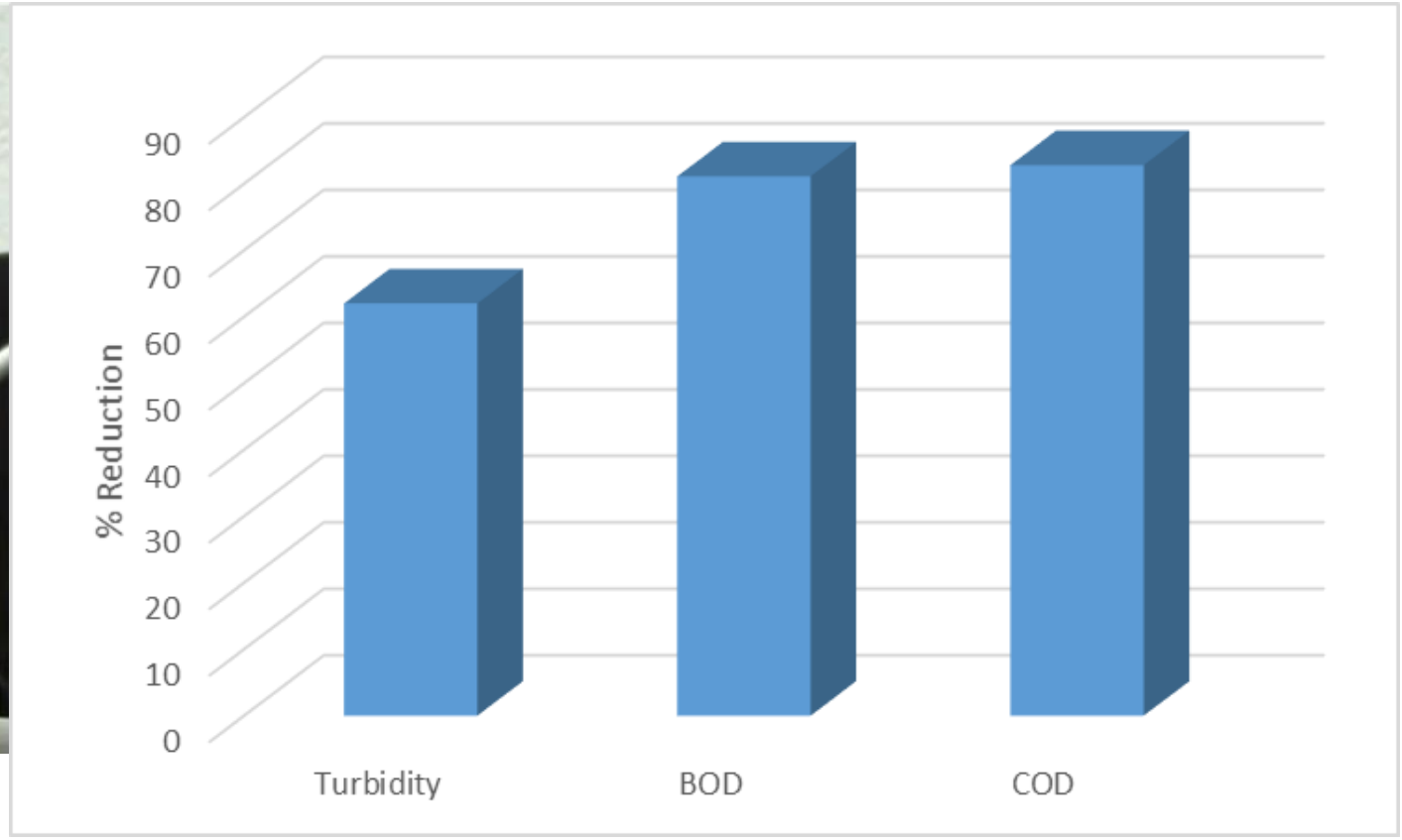
Waste Water

Water after Chemical Coagulation

Water following DAF Treatment

Electrocoagulation Treatment of Spent Lettuce Wash Water

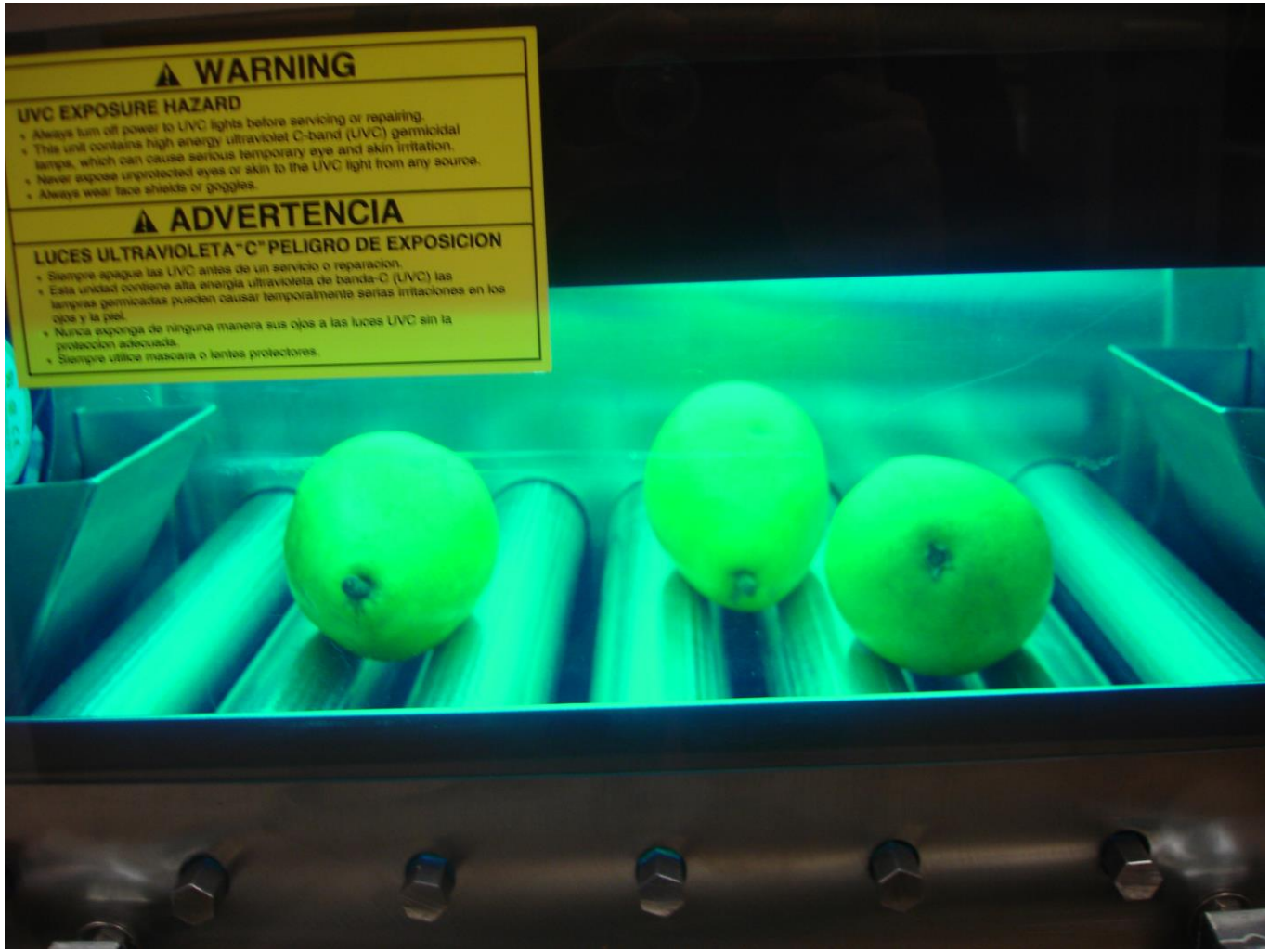




Alum Coagulating Agent

Coagulation - Filtration

Water-Free Systems



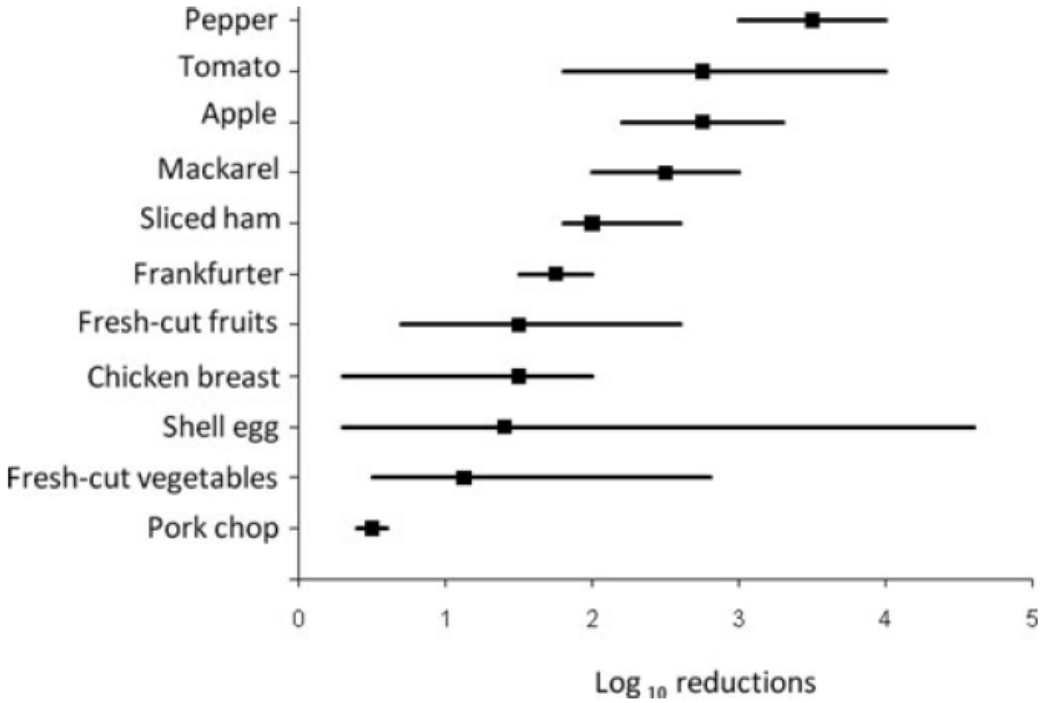
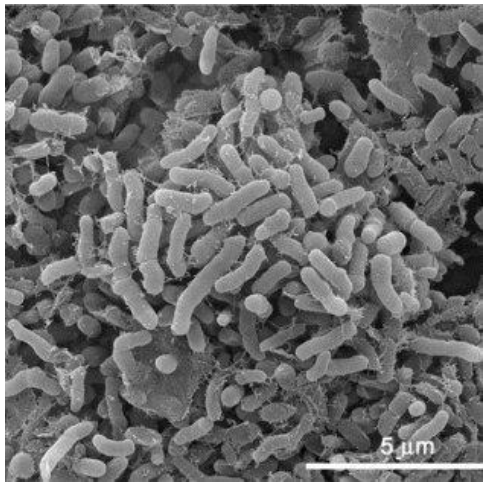
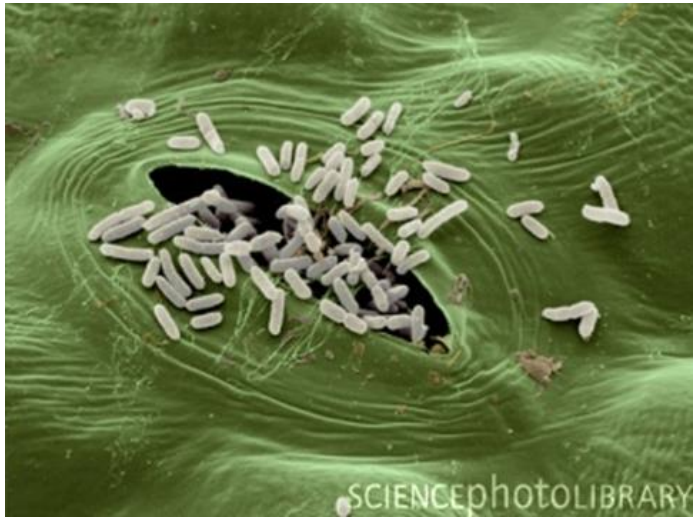


Figure 2 Logarithmic reductions achieved by exposure of different products to ultraviolet radiation (symbol: median, bar: minimum-maximum interval).

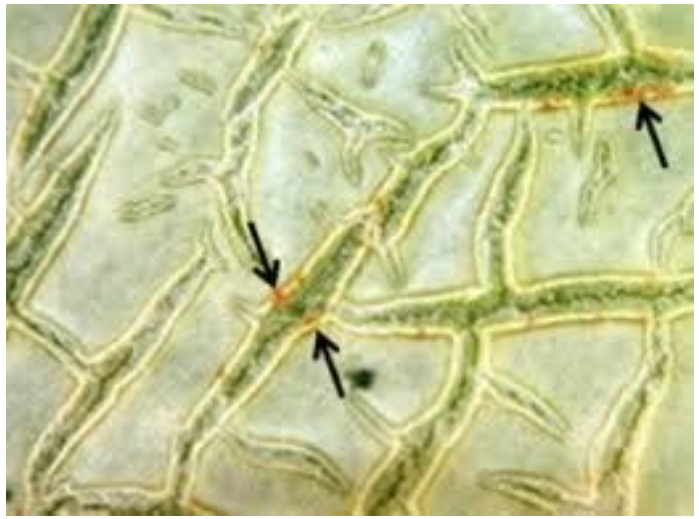


Biofilm

Stem Scar Tissue



Natural Openings and Cut Edges

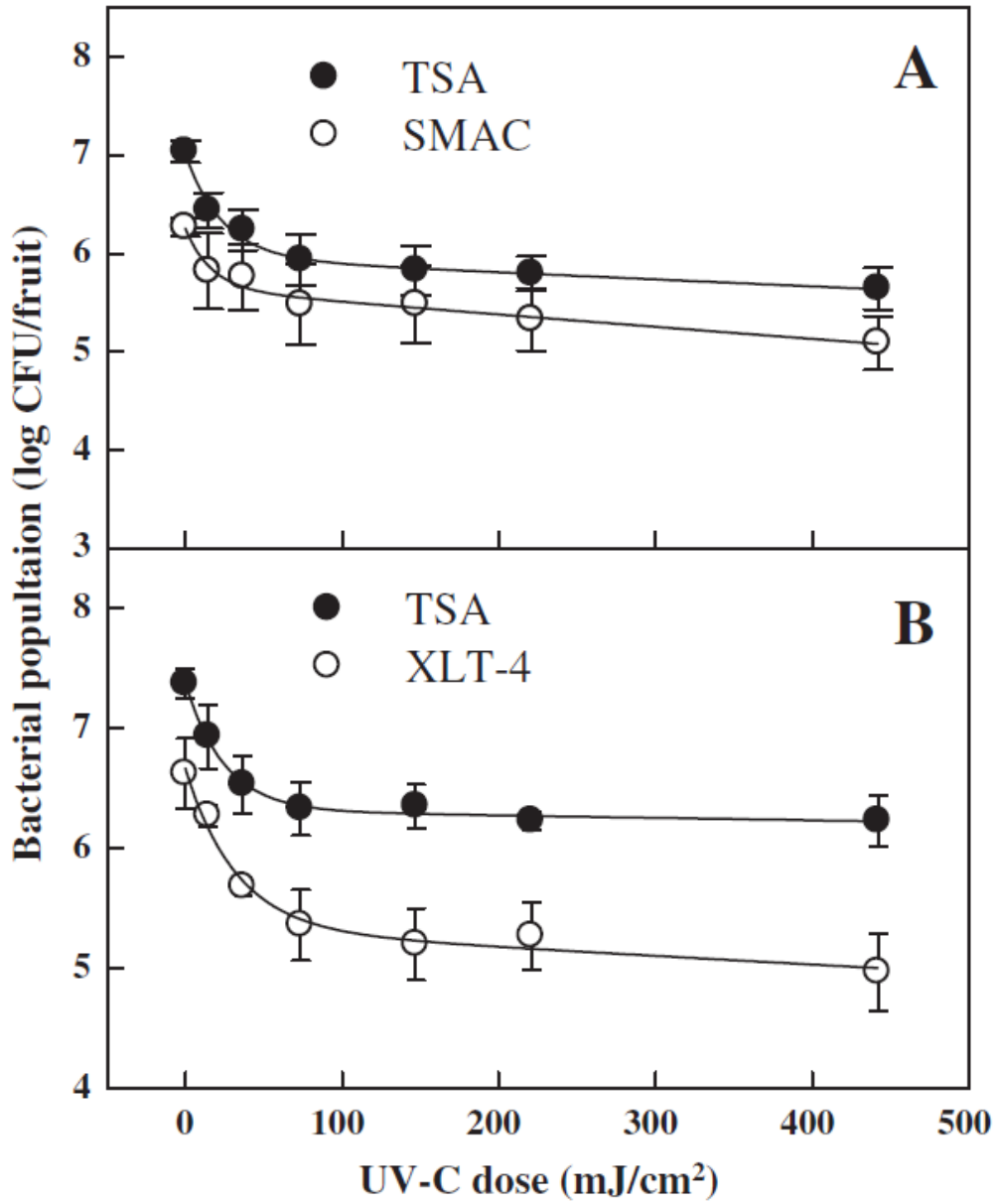


Internalization

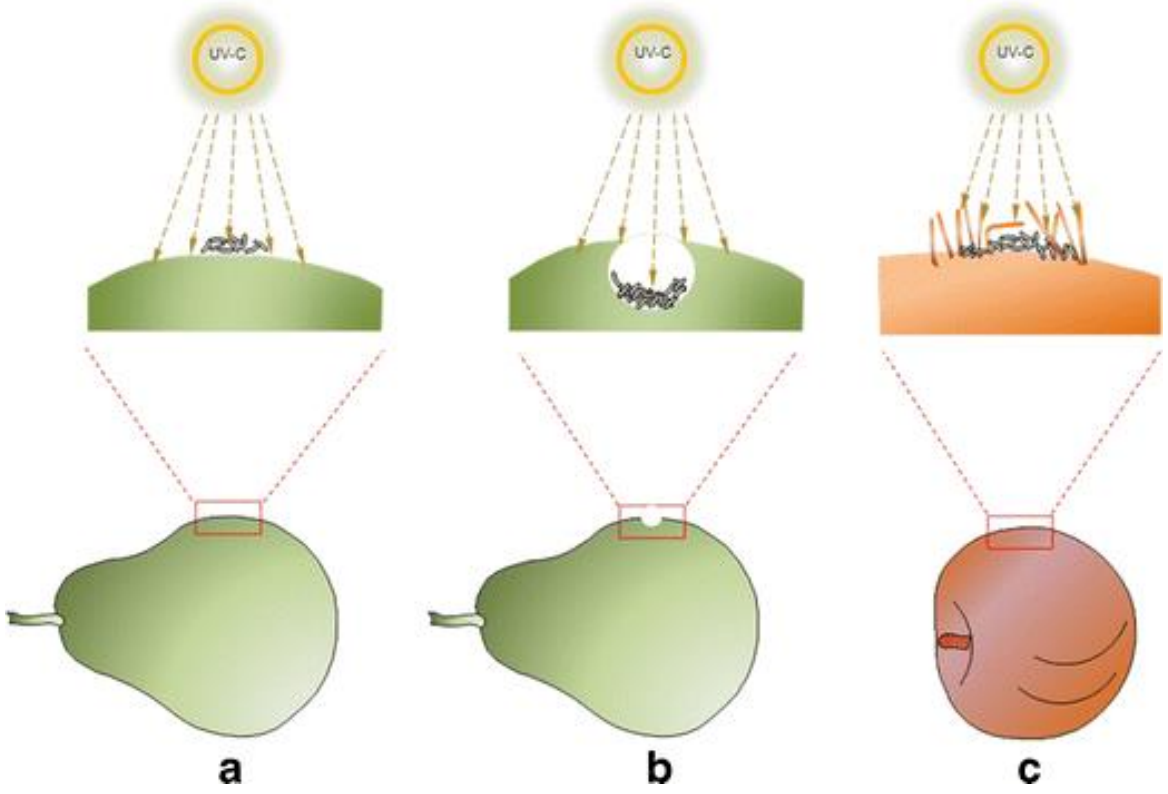
UV-C Treatment of Apricots

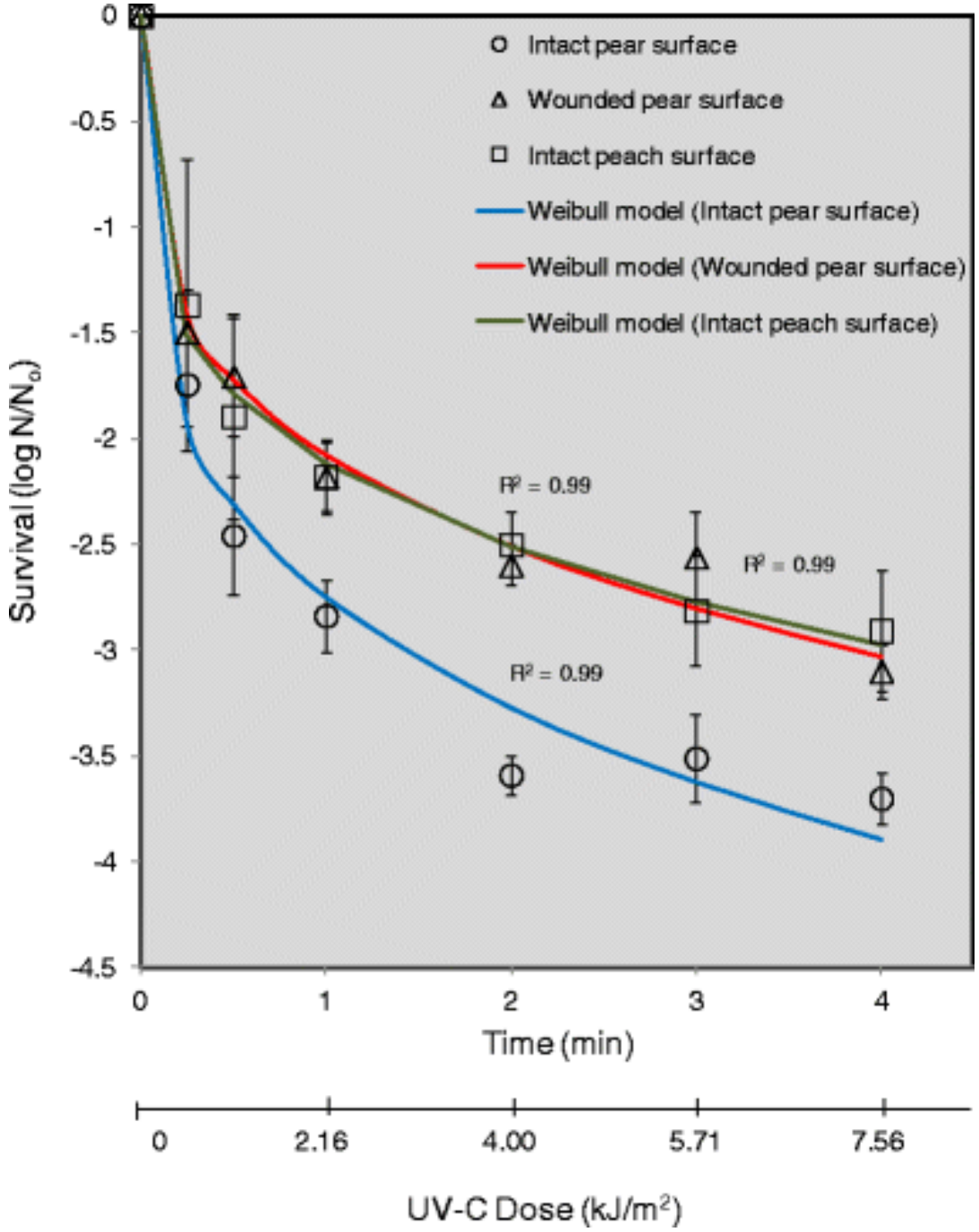
A: *E. coli* O157:H7
B: *Salmonella*

Yun et al., 2013



Inactivation of *E. coli*





Syamaladevi et al 2012

Overdose UV: Browning & Softening

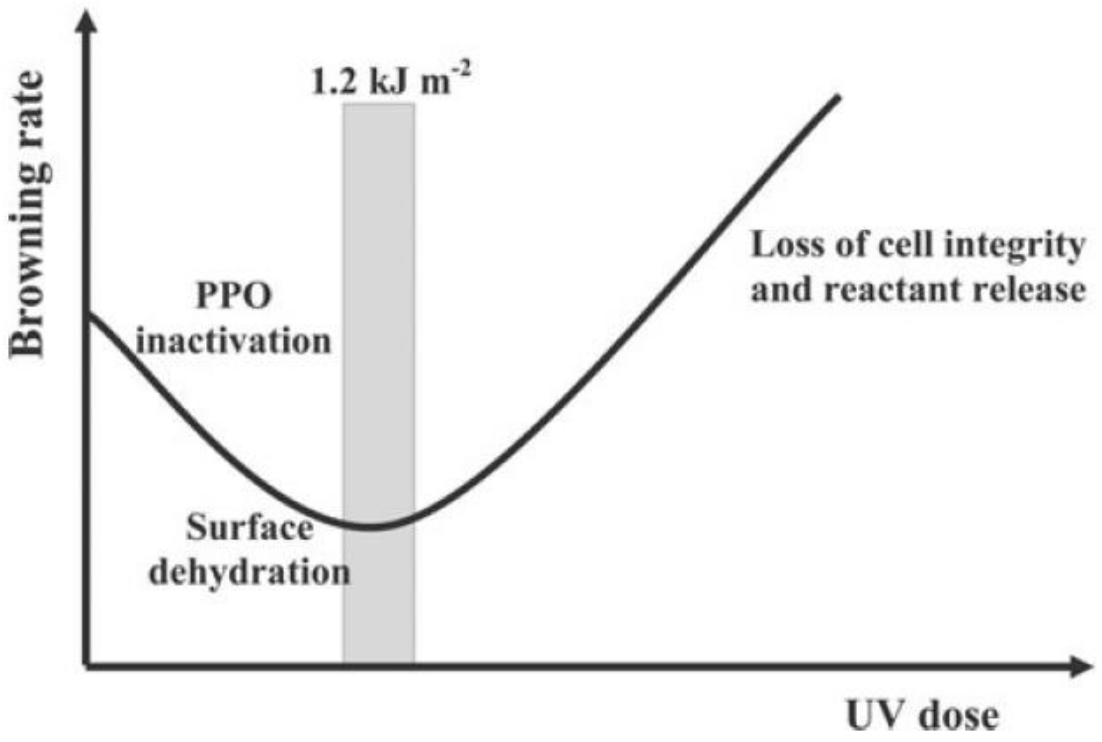


Figure 5 Schematic representation of the effect of UV dose on the events conditioning browning rate during storage of fresh-cut apple.

Enzyme activation

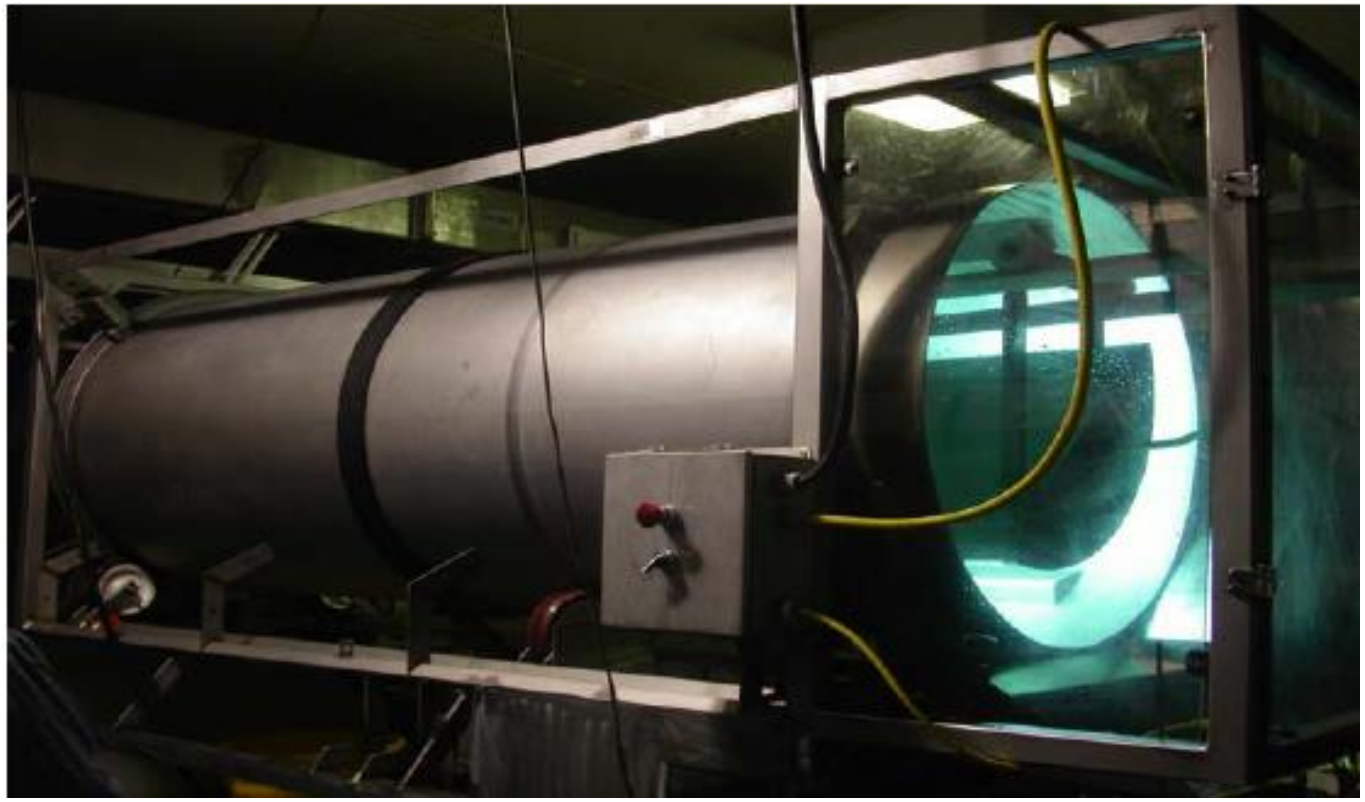
Depolymerization

Cellular collapse

Furan generation

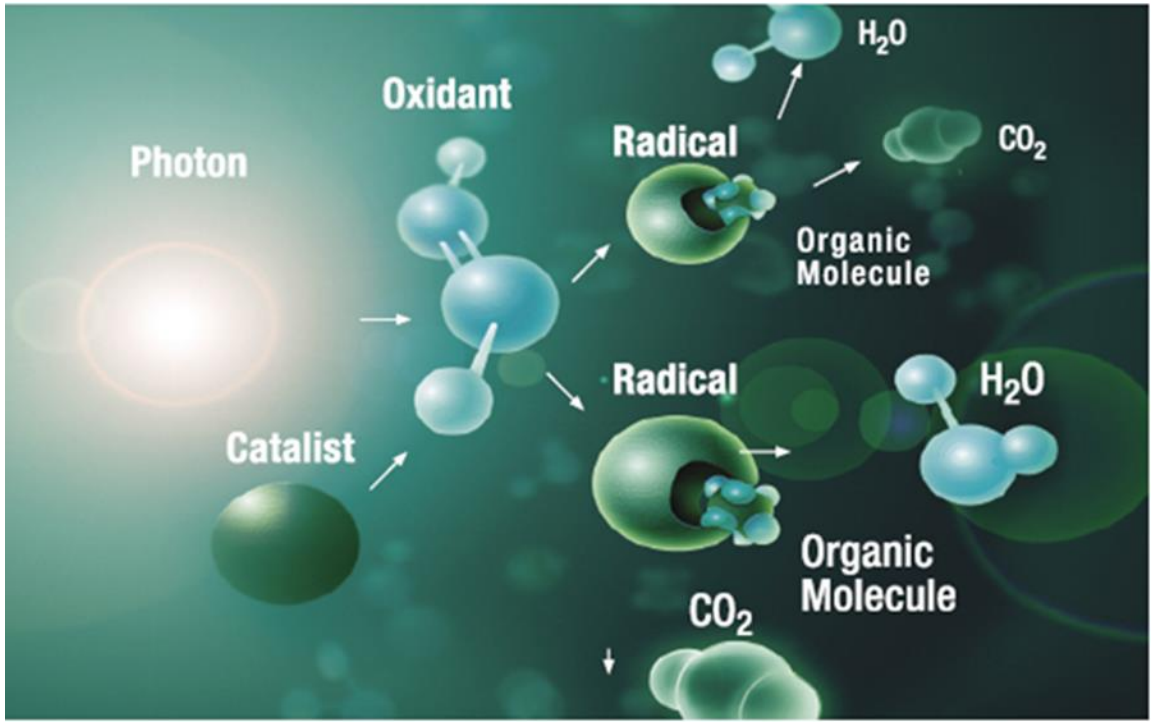
Manzocco and Nicoli, 2015

Tumbler UV Reactors

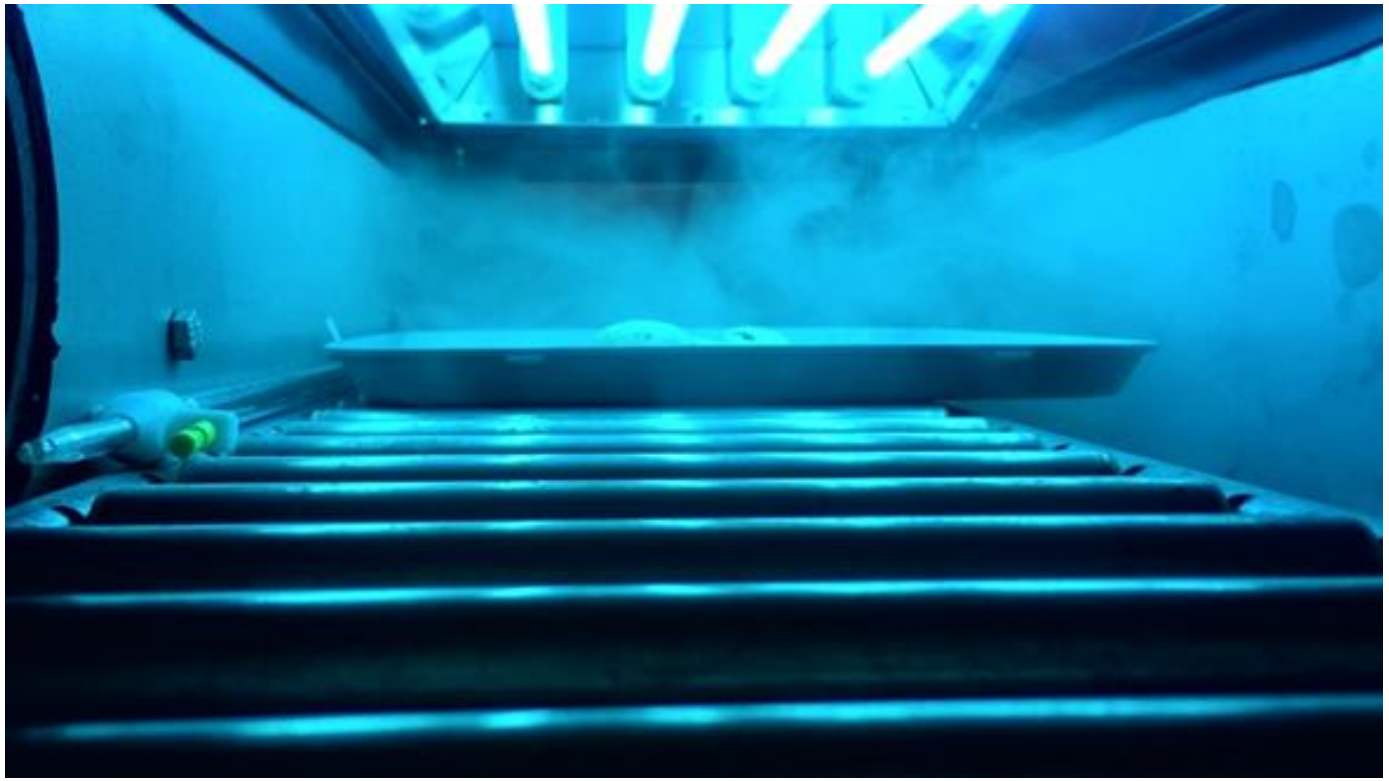


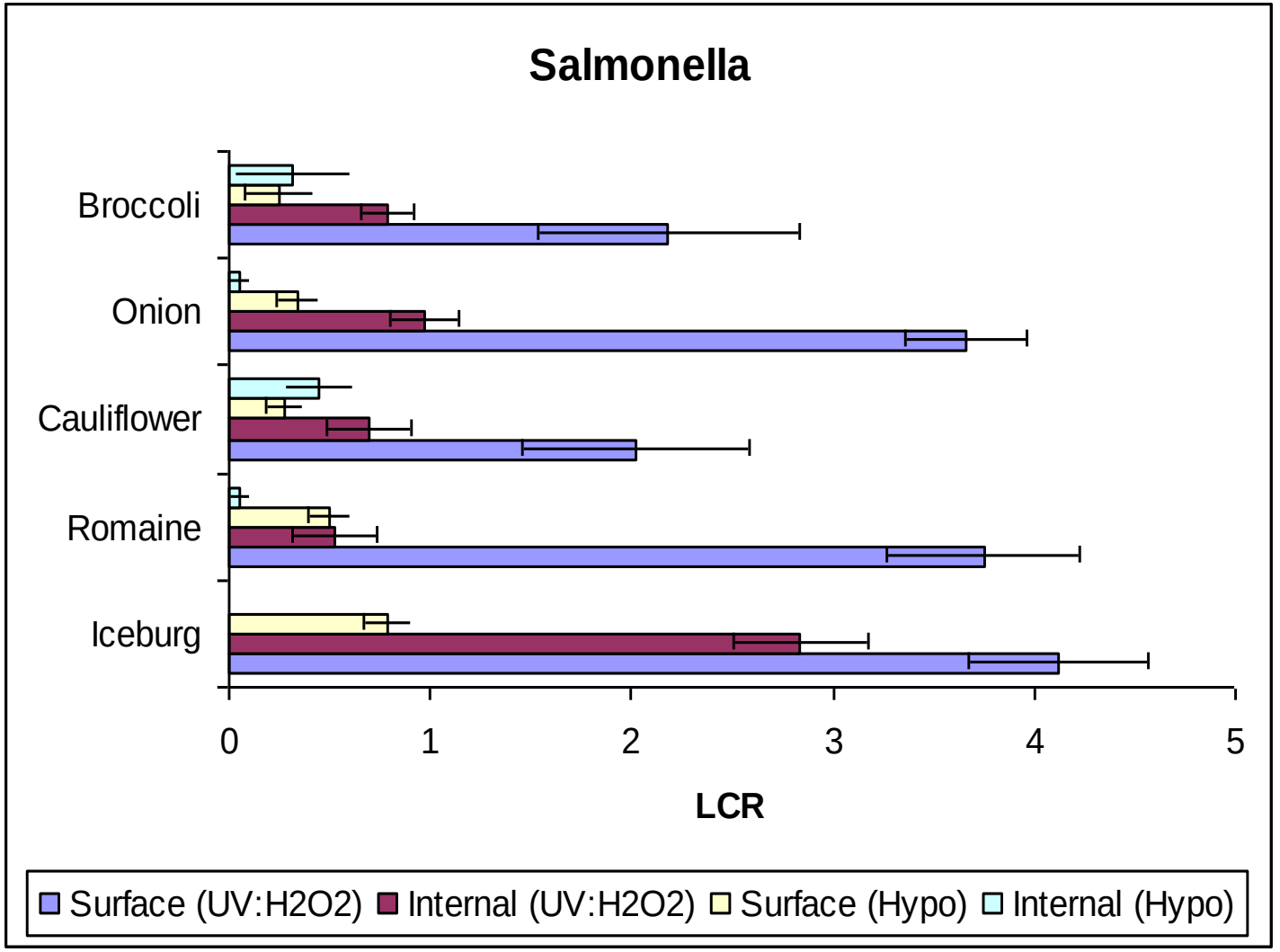
Advanced Oxidative Process

- Generation of oxidative free radicals
- UV:hydrogen peroxide
- UV:ozone
- Hydrogen peroxide:ozone
- UV:hydrogen peroxide:ozone



UV Hydrogen Peroxide – AOP




Salmonella
Broccoli
Onion
Cauliflower
Romaine
Iceburg
0
1
2
3
4
5
LCR
Surface (UV:H2O2)
Internal (UV:H2O2)
Surface (Hypo)
Internal (Hypo)

Commercial AOP unit

Take Home Message

- Preventive controls required under FSMA and likely SFCA
- FDA have set out guideline to assess Prevention Controls
- UV can be an additional intervention to enhance microbiological safety
- Challenges need to be addressed
  - Turbidity
  - Water treatment
  - Shading
  - Negative impacts on sensory
- AOP holds promise
- Multiple hurdles to form a firewall between primary production and processing
- Shelf-life extension is the main selling point to industry

Acknowledgements

- OMAFRA
- Mitacs OCE
- NSERC
- Collaborating Partners