

Life in the Dry: Food Safety and Risk Management Options Associated with Low Moisture Foods

Moderator: Siyun Wang, University of British Columbia

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Today's Speakers

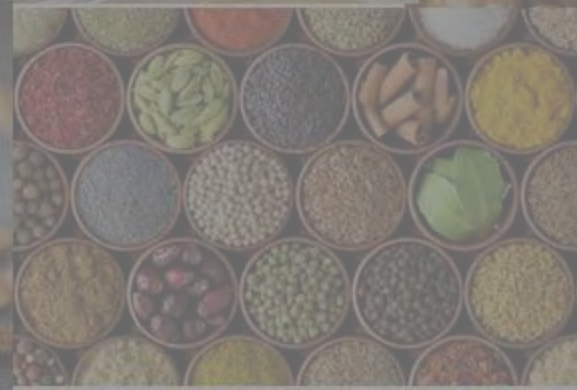
- Keith Warriner, University of Guelph
- Jennifer C. Acuff, University of Arkansas

Life in the Dry: Food Safety and Risk Management Options Associated with Low Moisture Foods

Dr Keith Warriner

Department of Food Science

University of Guelph



Acknowledgments



Ministry of Agriculture,
Food and Rural Affairs

CLĒAN works



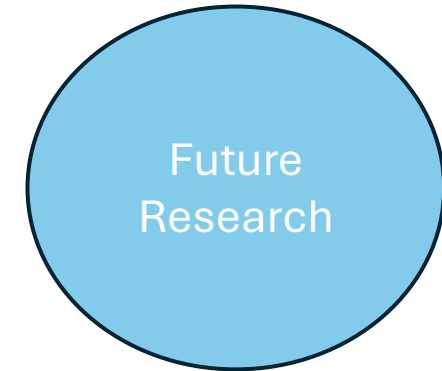
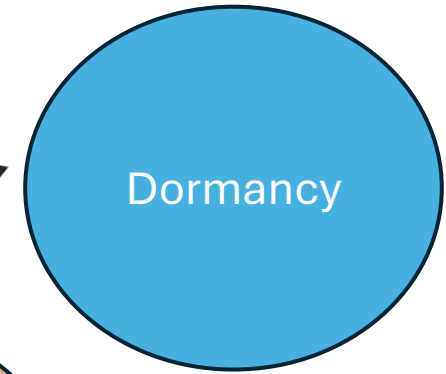
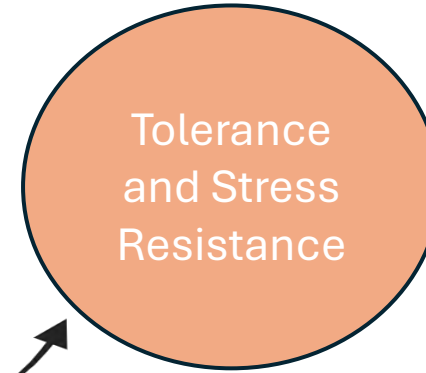
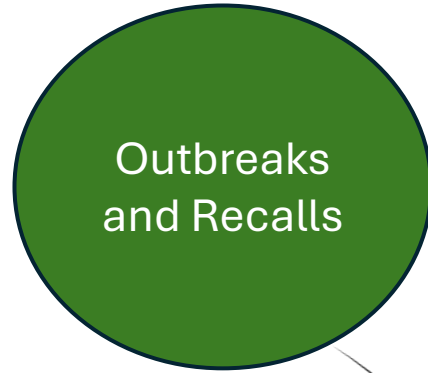
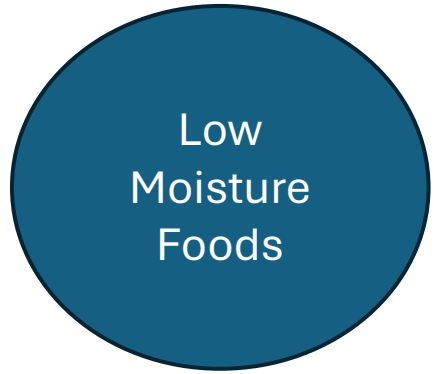
**NSERC
CRSNG**



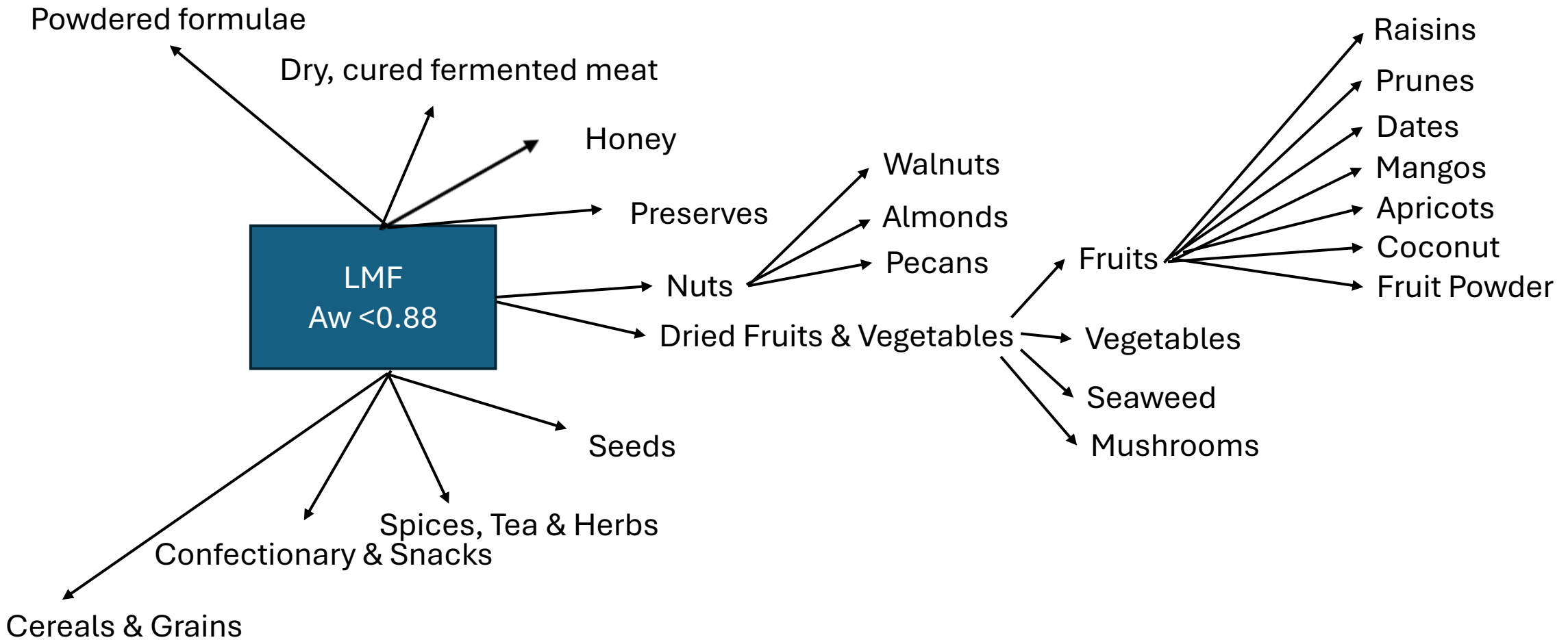
WESTON GEORGE
WESTON
LIMITED



Outline



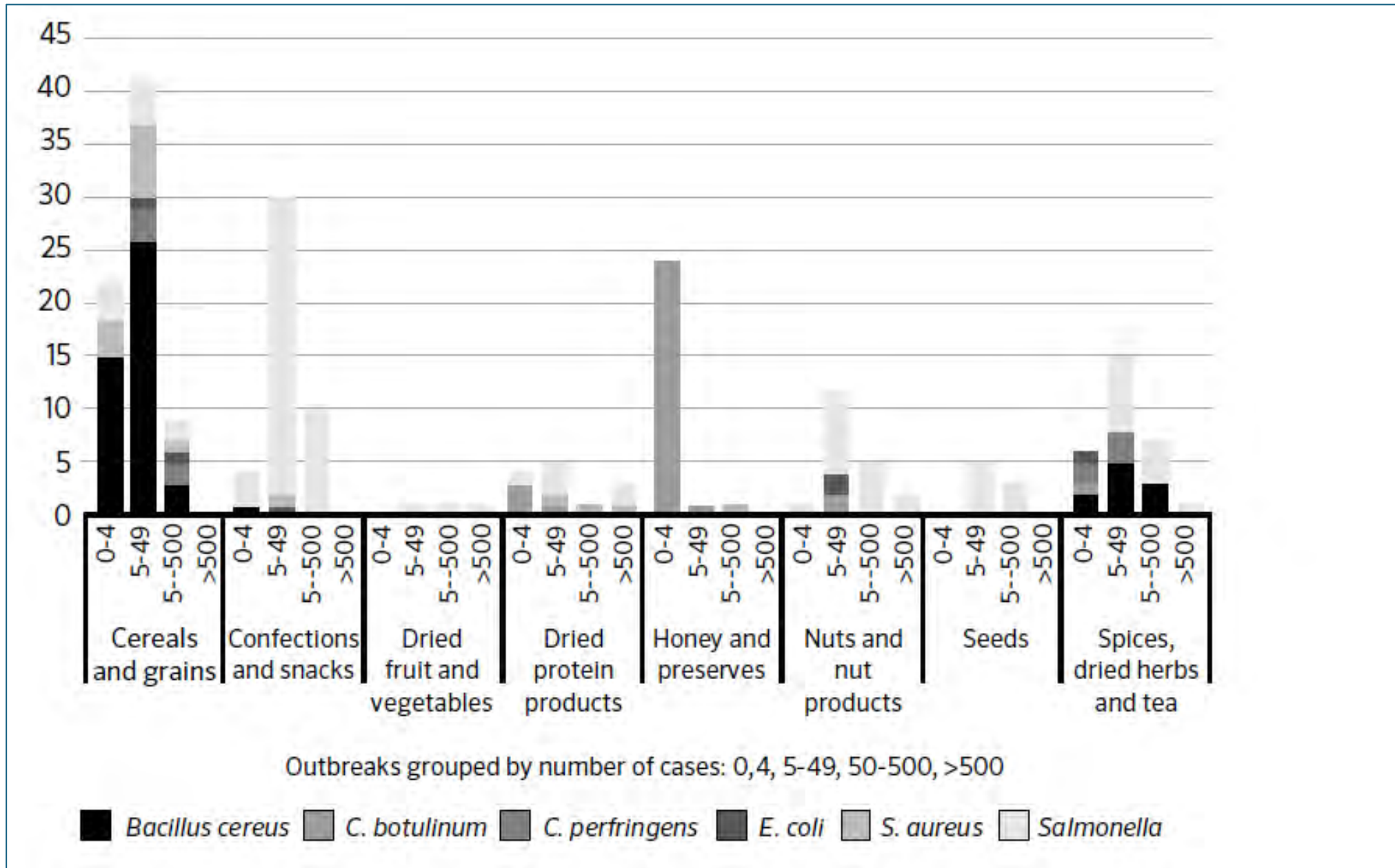
Low Moisture Foods ($A_w < 0.88$)



Pathogen Burden of LMF

% (count)	Outbreaks	Cases	Hospitalizations	Deaths
<i>Salmonella</i> spp.	44.9% (96)	43.8% (12 415)	88.6% (895)	73.7% (14)
<i>E. coli</i>	2.3% (5)	1.2% (354)	3.3% (33)	5.3% (1)
<i>B. cereus</i>	25.7% (55)	3.7% (1057)	1.4% (14)	0% (0)
<i>C. botulinum</i>	15.0% (32)	0.3% (84)	6.0% (61)	21.1% (4)
<i>C. perfringens</i>	4.7% (10)	1.5% (432)	0% (0)	0% (0)
<i>S. aureus</i>	7.5% (16)	49.4% (14 006)	0.7% (7)	0% (0)
<i>L. monocytogenes</i>	0% (0)	0% (0)	0% (0)	0% (0)
<i>Cronobacter</i> spp.	0% (0)	0% (0)	0% (0)	0% (0)
<i>Enterobacteriaceae</i>	0% (0)	0% (0)	0% (0)	0% (0)

Source Attribution and Magnitude of Outbreaks



OUTBREAK UPDATE
SALMONELLA INFECTIONS



WHAT TO DO Read the updated public health notice and follow the advice in it to help reduce your risk of a Salmonella infection.

CANADA.CA/HEALTH 



Food Poison Journal

Infant Formula recalled due to Cronobacter

MARLER CLARK
THE FOOD SAFETY LAW FIRM

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Norwegian Salmonella outbreak traced to dried fruit from multiple countries

By News Desk on April 21, 2021

A dried fruit mix linked to an outbreak of Salmonella in Norway contained products from South East Asia and Africa, according to researchers.



Food Safety News

Salmonella found in Finnish spice controls

FSN



Food Safety News

Great Value chia seeds recalled because of Salmonella

FSN



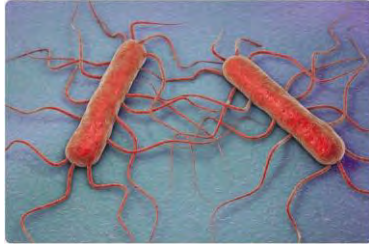
Outbreak Investigation of Salmonella: Peanut Butter (May 2022)

Outbreak over; FDA issues a warning letter.

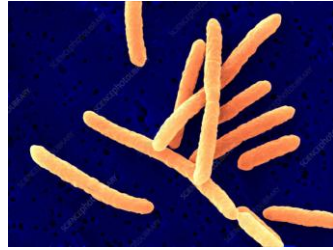
Hazards



Salmonella



Listeria monocytogenes



Toxigenic *Escherichia coli*



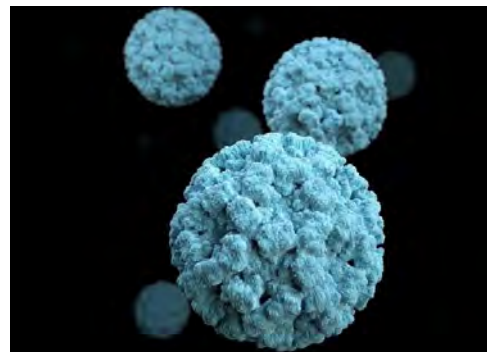
Bacillus cereus



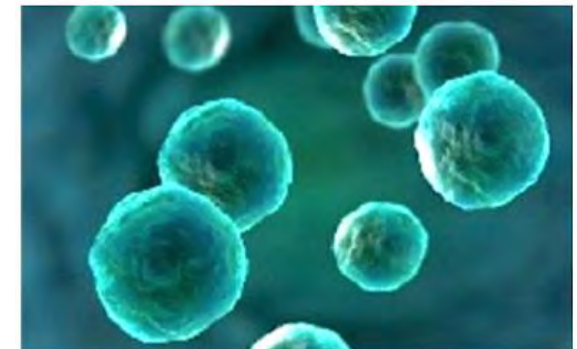
Cronobacter sakazakii



Molds (Mycotoxins)



Enteric Viruses



Enteric Protozoan

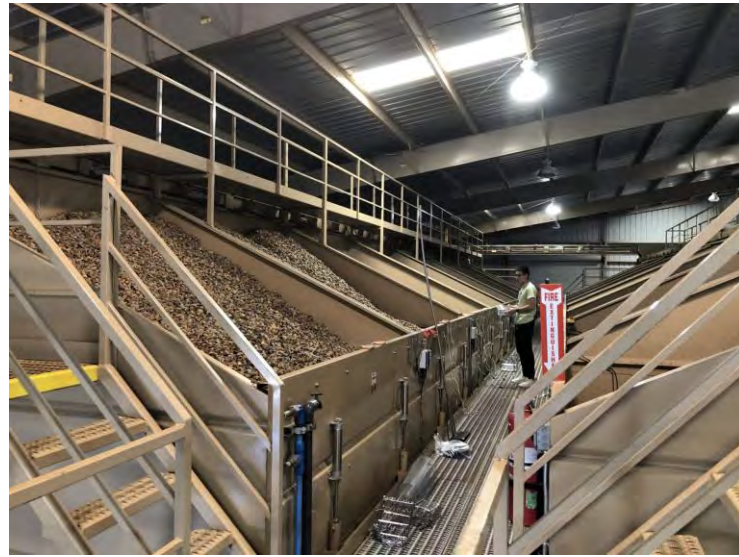
Tree Nuts



Soil
Irrigation water/rain
Animal activity
Contact surfaces

Ground Nuts





Post-harvest
Post-harvest drying
<7% Moisture



Storage
Constant conditions



Processing
Contact surfaces
Air
Biofilms





Pre-harvest

Irrigation water
Organic amendments
Animal activity



Harvest

Soil
Contact surfaces
Dust



Receiving and Washing

Wash water
Contact surfaces



Slice
Antioxidant dip



Drying

Contact Surfaces

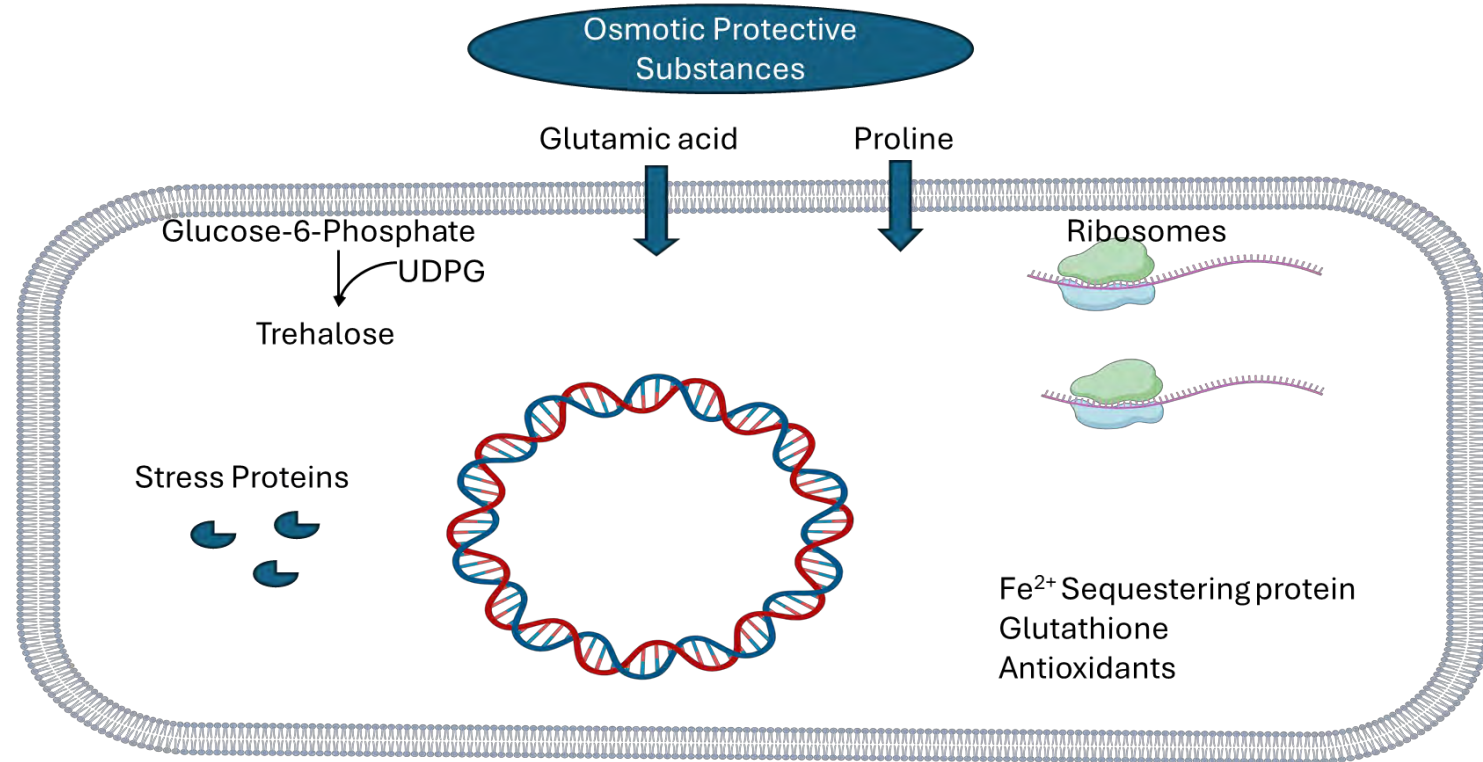


Life in the dry

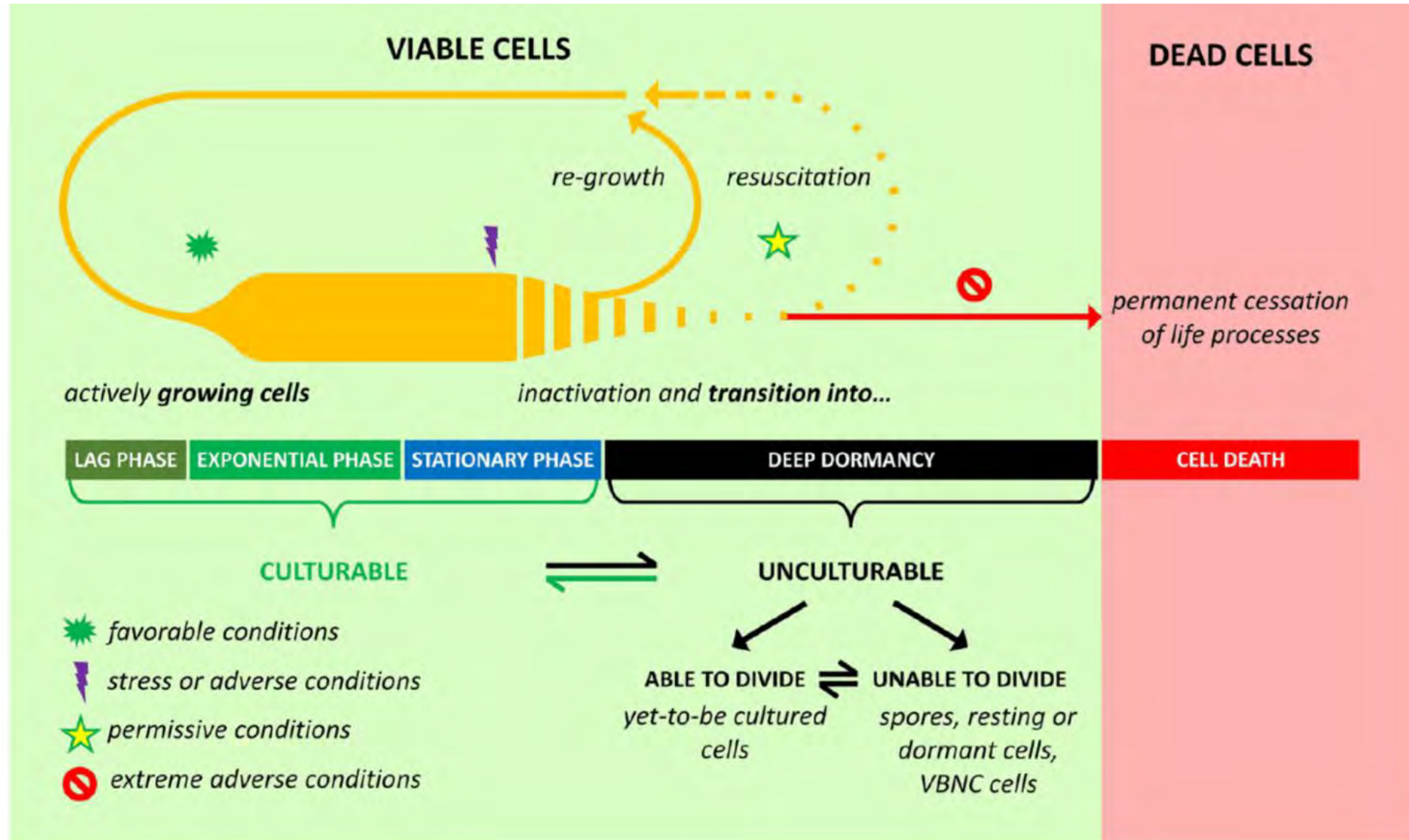


Response to low water activity

- RpoS
- Increased expression
- Ribosomes
- Cytoplasmic protein
- tRNA hydrolayse
- Increase virulence
- Osmotic protective substance
- Trehalose synthesis
- Heat shock proteins
- Anti-oxidant accumulation/synthesis

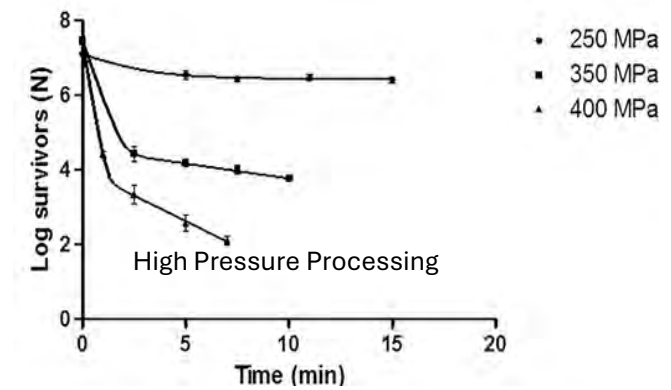
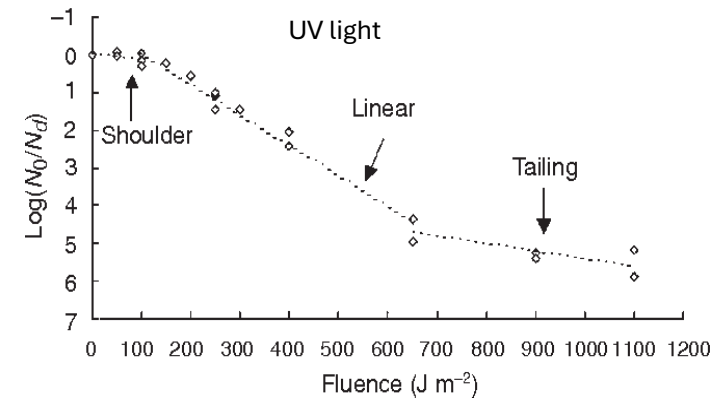
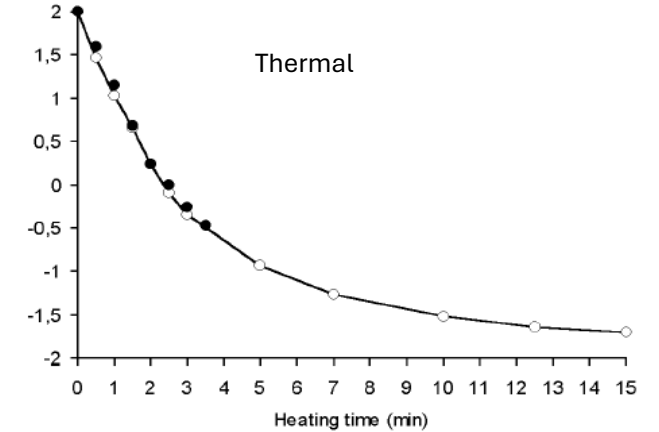
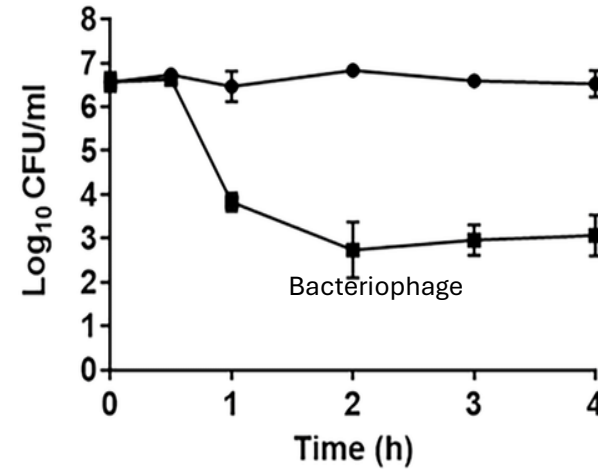


Dormancy: Ultimate Survival Strategy



Populations are heterogenous

- Resistant subpopulations
 - Antibiotic exposure
 - High pressure processing
 - Thermal treatment
 - UV
 - Bacteriophages
 - Sanitizer resistance
 - Long term survival
- Latent infections
- Biofilms
- Sensitivity of growing cells vs stationary
- Disconnect between laboratory data and natural environments



■ Reflex culture positive

■ Reflex culture negative

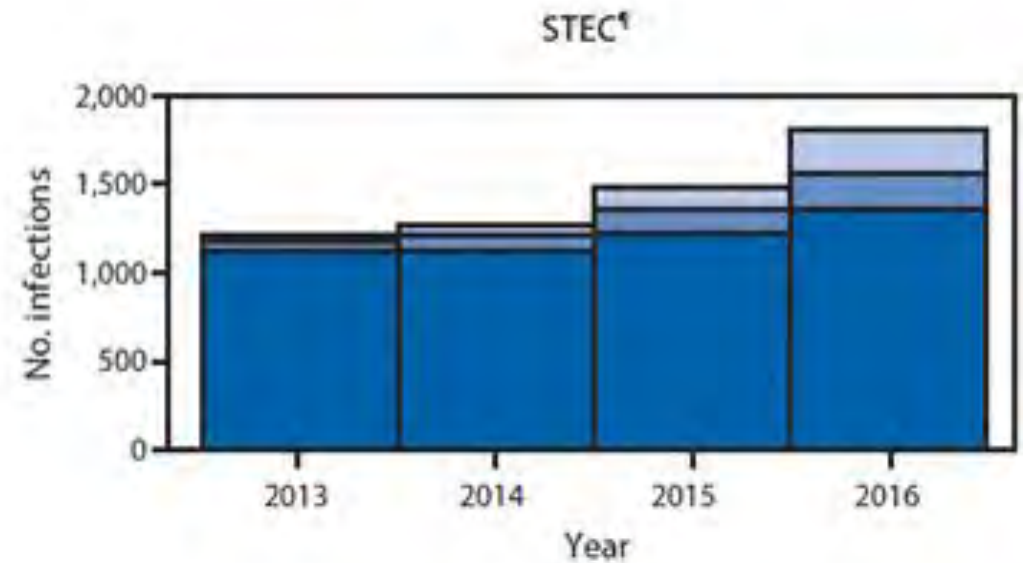
■ Reflex culture not performed

Delayed or no growth

False negatives

PCR positive culture
negative

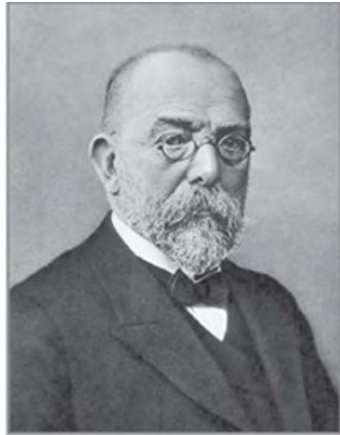
Clinical, food and
environmental samples



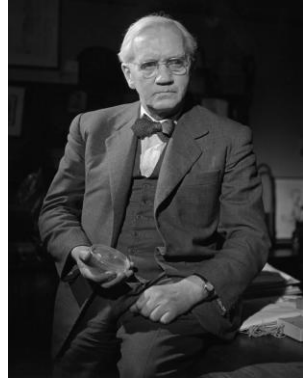
A Brief History of Dormancy



Louis Pasteur 1857
Germ Theory



Robert Koch 1890
Postulates



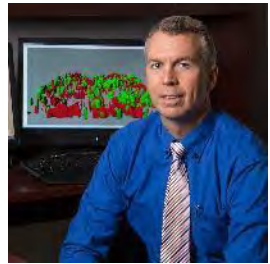
Alexander
Fleming
1928
Antibiotics



Joe Bigger &
Stanly Steward
1944
Persister Cells

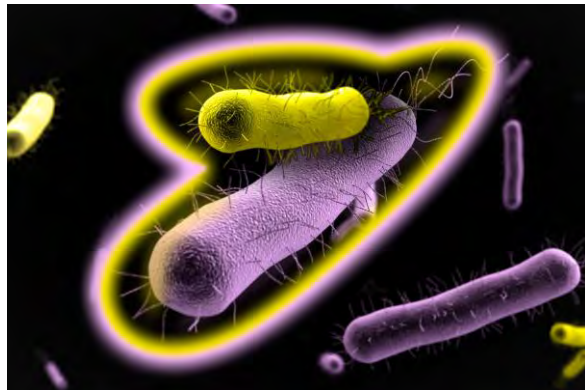
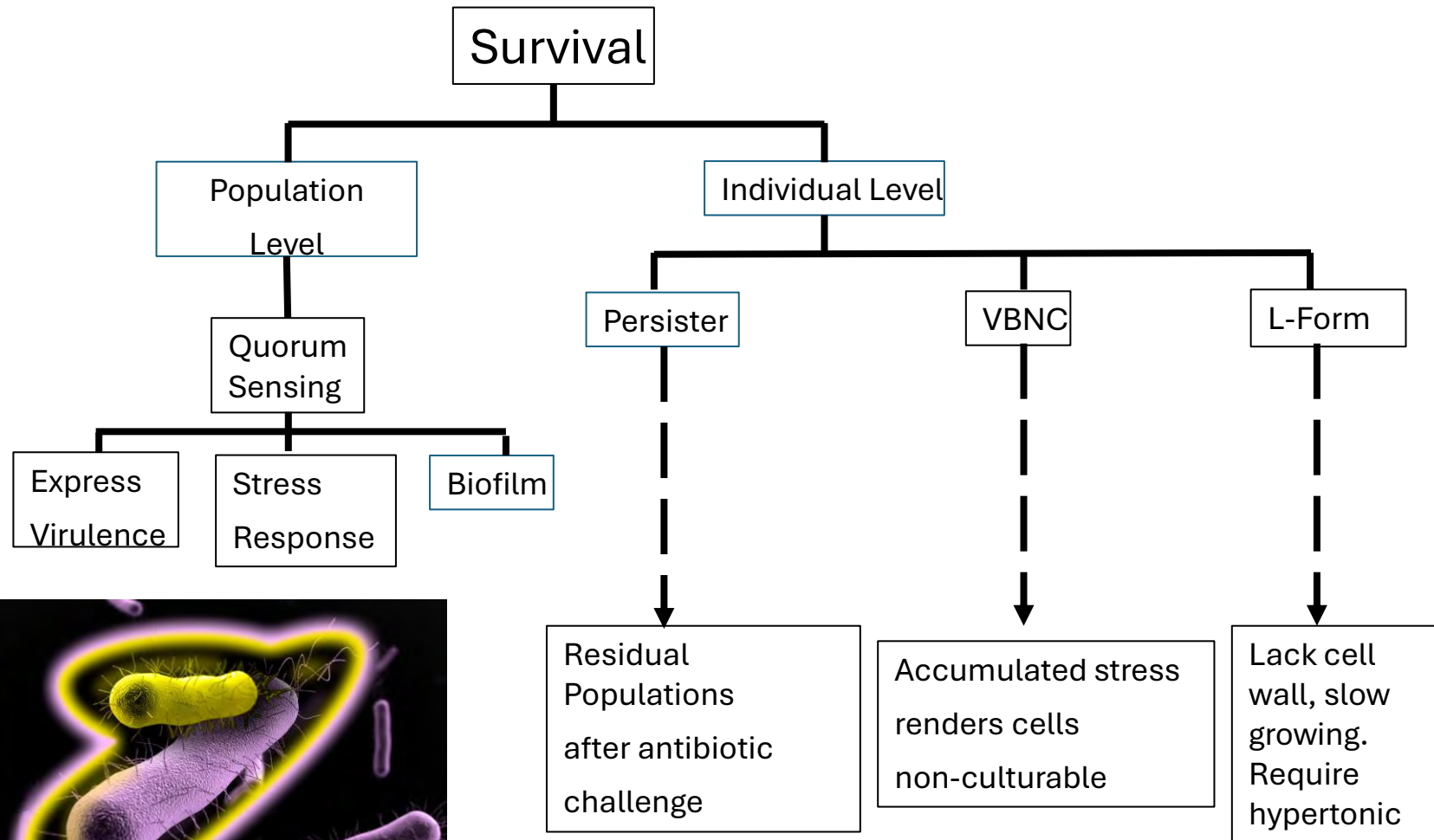


Rita
Colwell
1982
VBNC



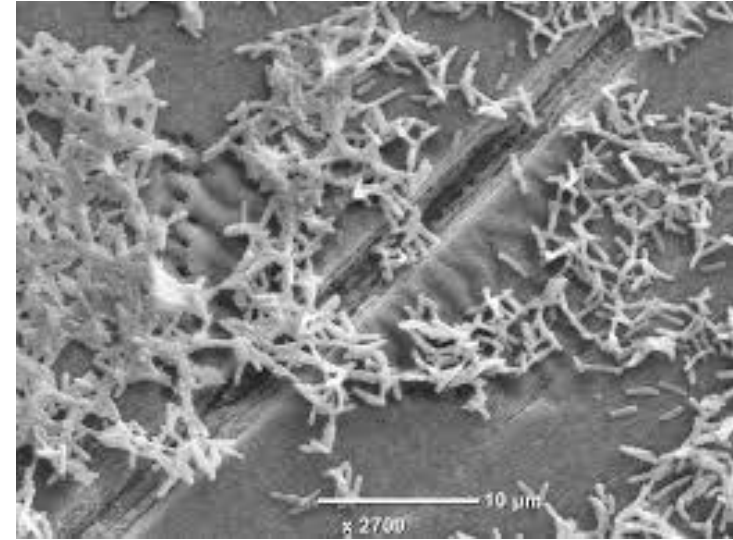
Tom K Wood
2004
Persister
Mechanisms

“Most bacterial cells lead lives of quiet desperation in biofilms, combatting stress; yet, their prevalence attests to their ability to alter gene regulation to cope with myriad insults”
Wood, 2018.



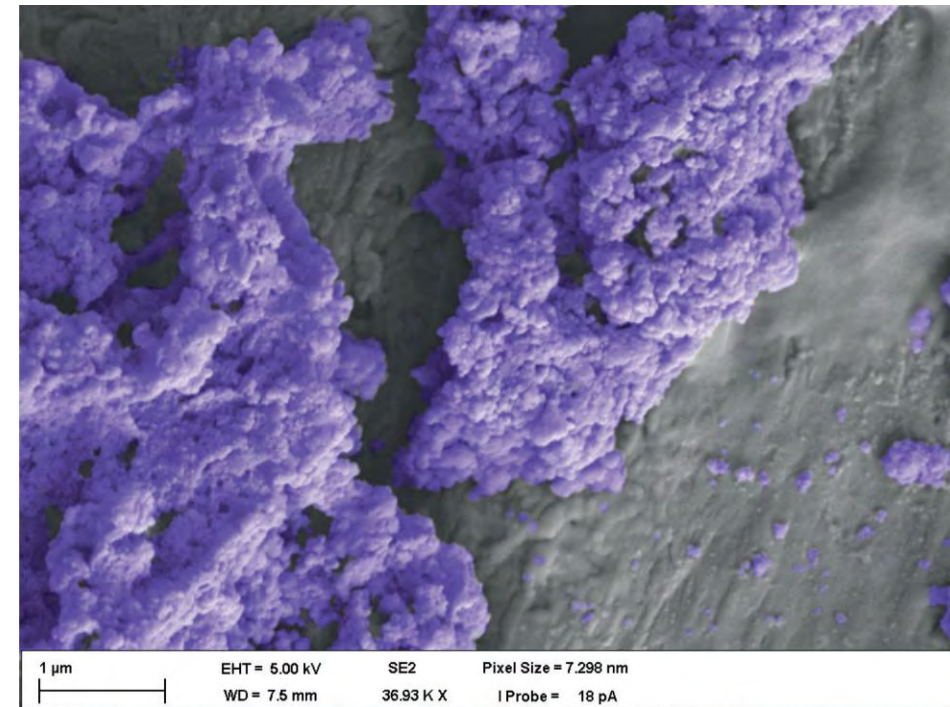
Dormant Cells

- Biofilm formation
- Low metabolic rate
- Latent infections
- Increased stress tolerance
 - Thermal
 - Sanitizers (e.g. isopropyl alcohol)
 - UV-C
 - Antibiotics
- Increases sensitivity to oxidative stress



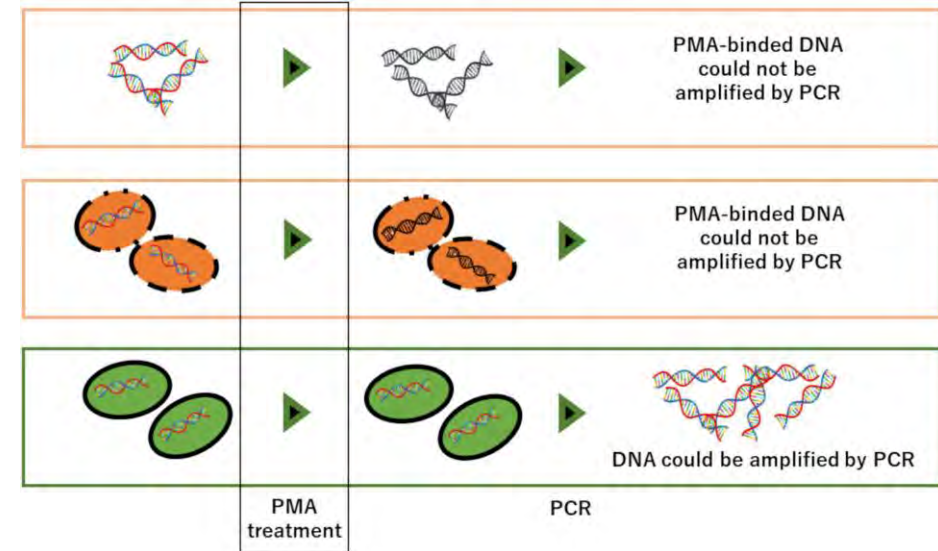
Dry Biofilms

- 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



Enumeration of Dormant Cells

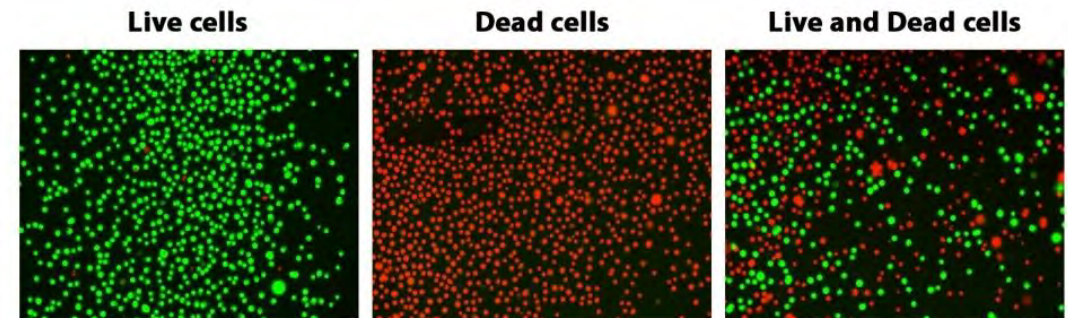
- PMA-PCR



- Viability staining Flow Cytometry

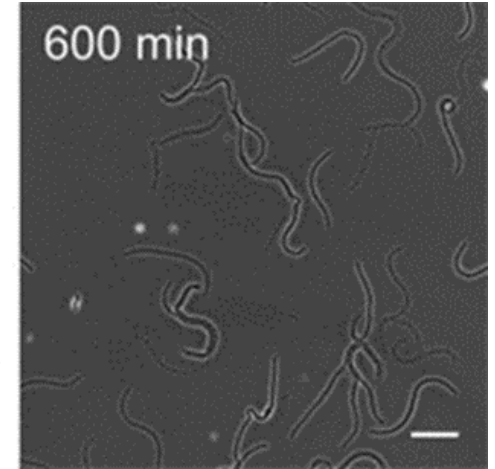
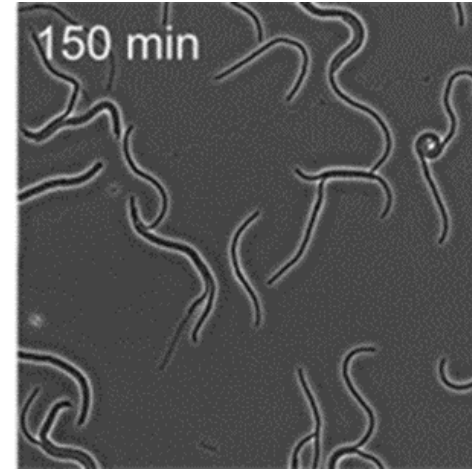
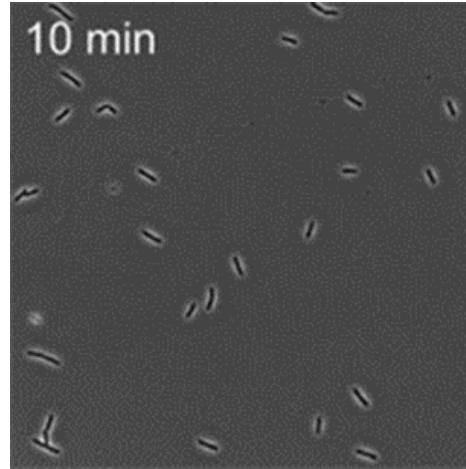
- Diffusion across depolarized membranes
- DNA binding protein

Neither method is reliable



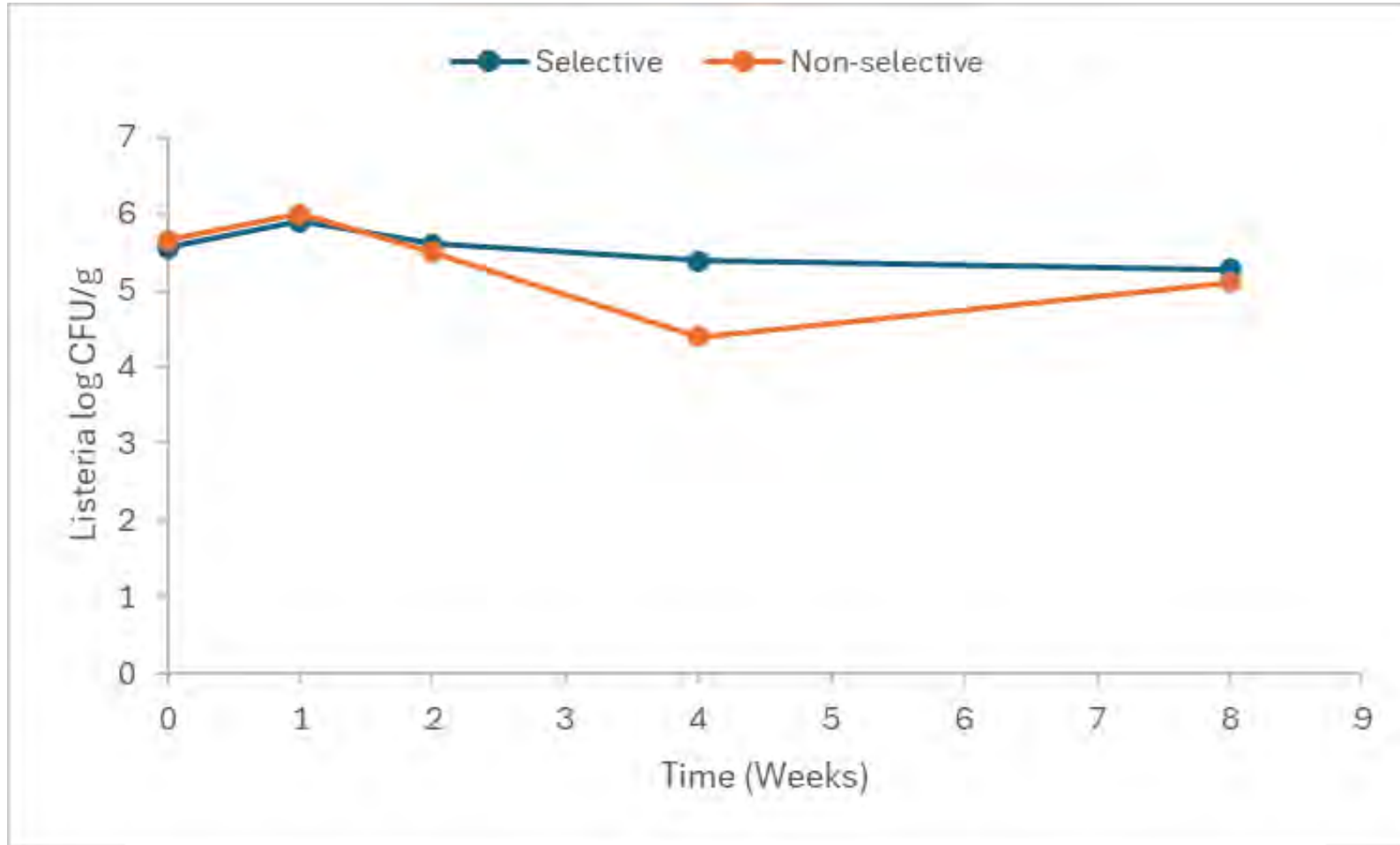
Enumeration by revival of dormant cells

- Reviving agents
 - Pyruvate
 - Methyl-pyruvate
 - Mannitol
 - Glucose
 - Signal molecules
 - Catalase
- *In vivo* (gastro-intestinal tract, macrophage)
- Time (Scout theory)

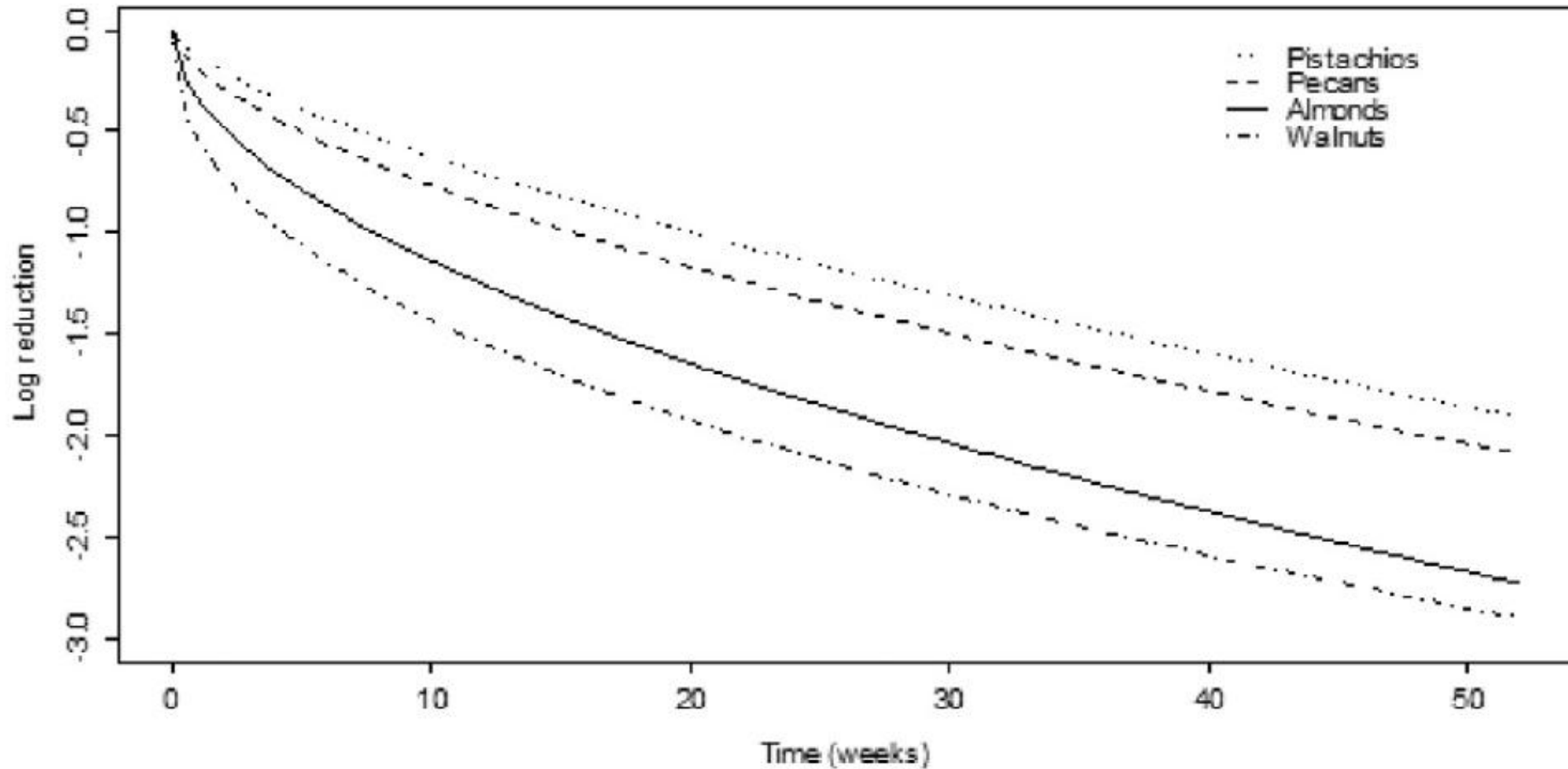


Fate of Pathogens on LMF

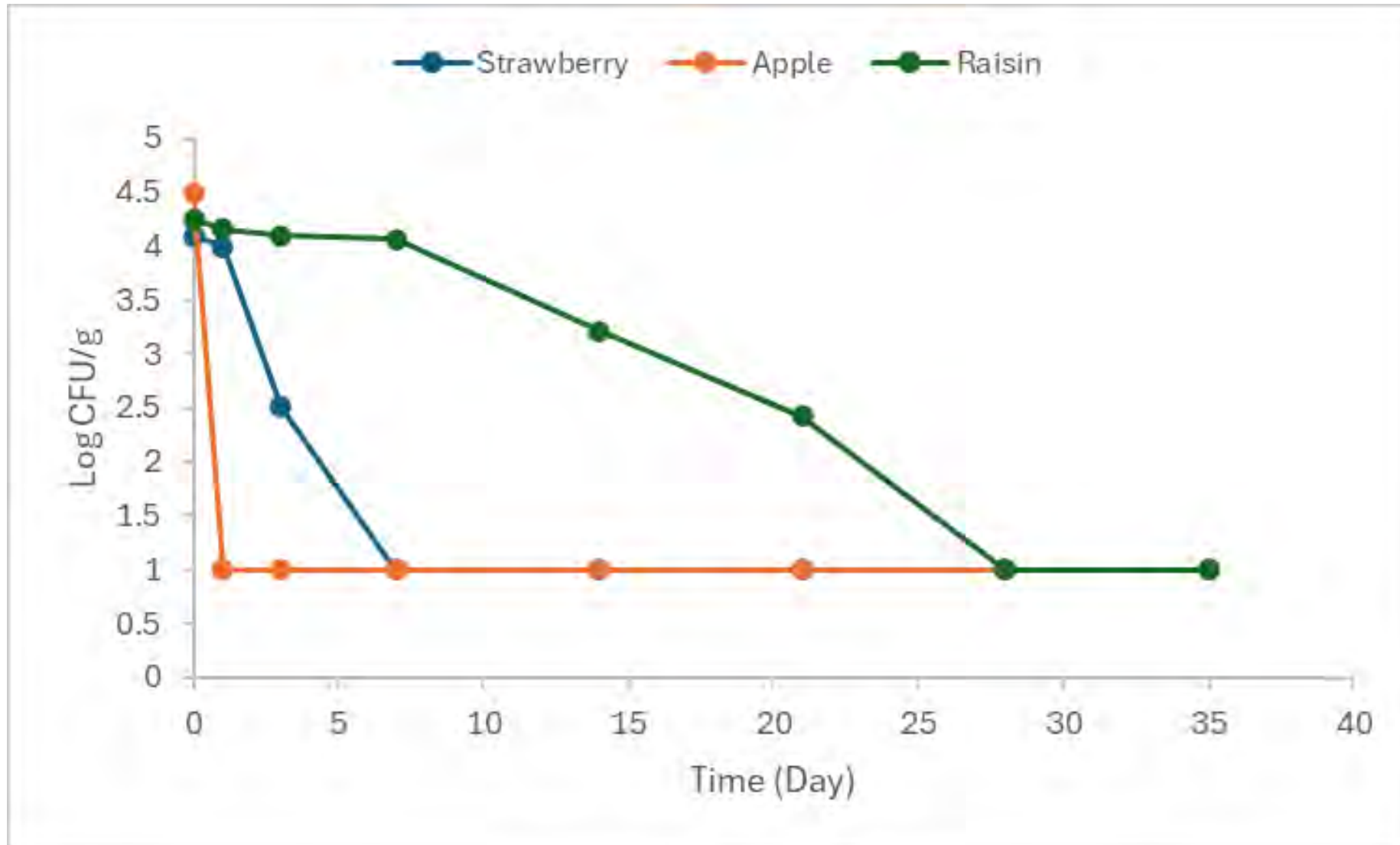
Listeria monocytogenes on Dry Roasted Shelled Pistachios



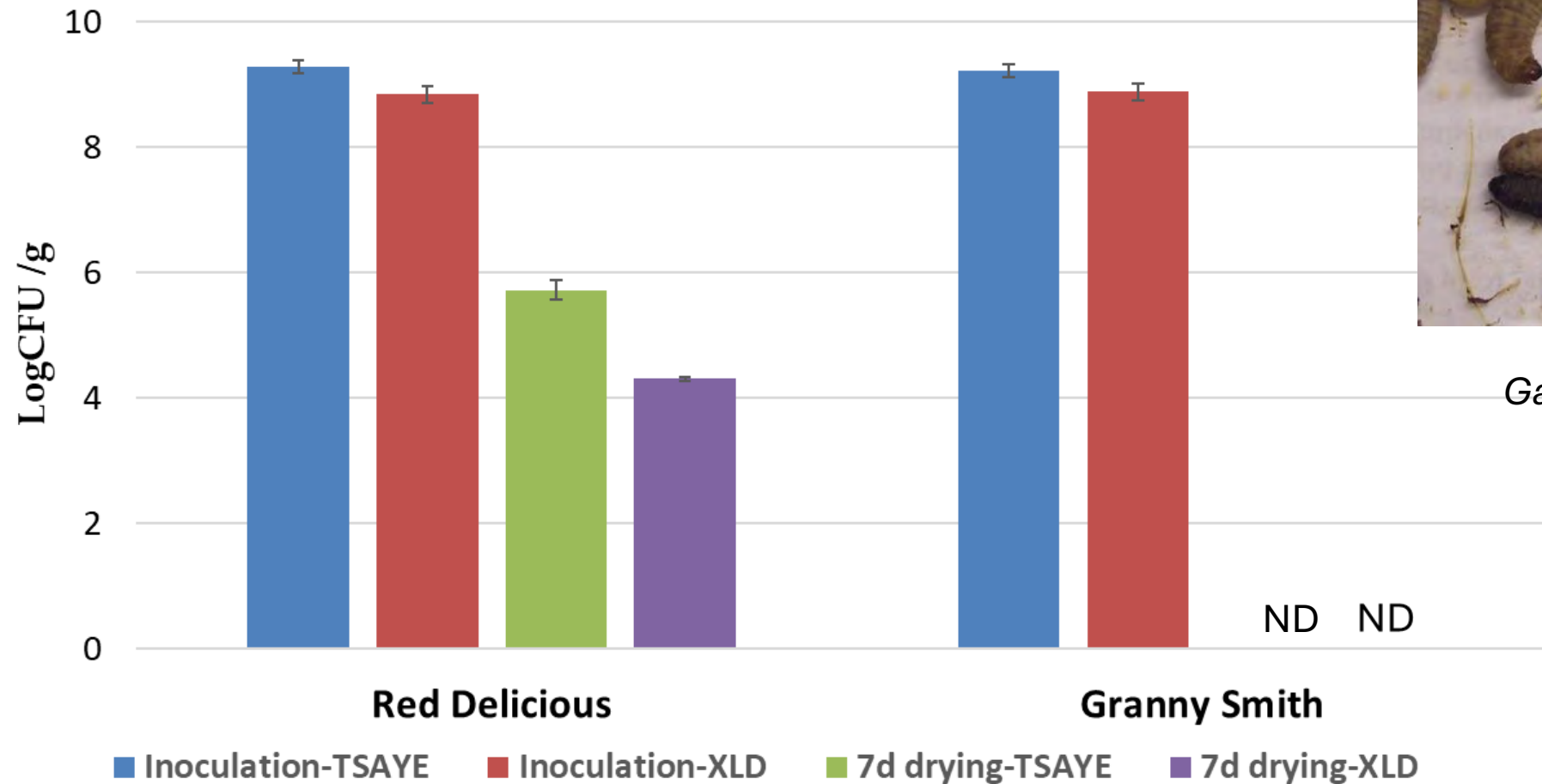
Salmonella Survival on Nuts



Listeria monocytogenes on dried fruit



Salmonella on dried apple



Galleria : Virulence test

Risk Management

A ¢ spent is a \$ saved

Good Agricultural Practice

- Site history: Chemical hazards (heavy metals)
- Water source: Fit-for-Purpose
- Land Management: Minimize animal intrusion
- Nutrient management: Composted manure
- Sanitary equipment: Bins, cutting tools



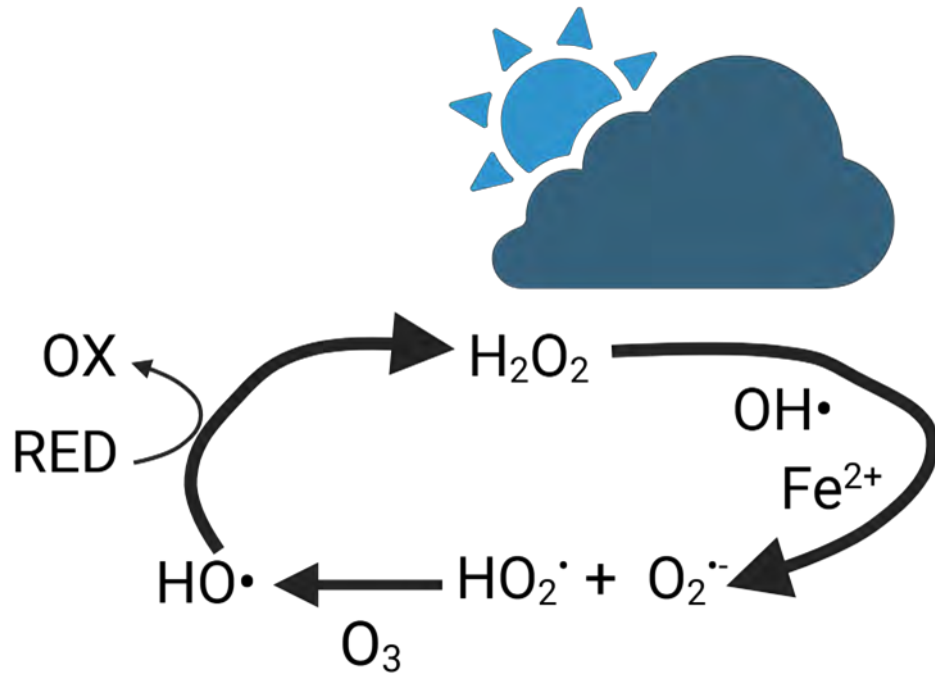
Mold Management

- Molds
 - Spoilage
 - Mycotoxins
-
- Adequate drying and storage
 - Transgenic plants
 - Biocontrol
 - Non-mycotoxin producing molds (competitive inhibition)
 - Lactic acid bacteria
 - Essential oils



Gas Phase Hydroxyl-Radical Process

Hydroxyl-radicals



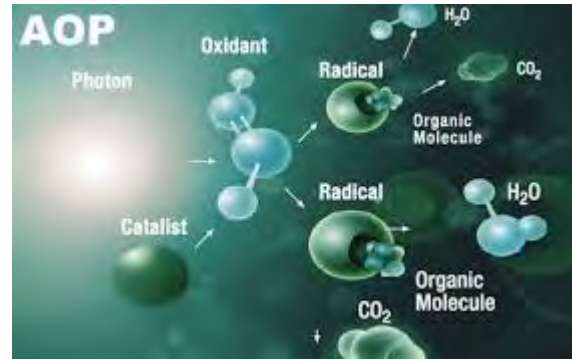
Oxidant	Oxidation Potential (V)
Fluorine [F ₂]	3.0
Hydroxyl radical [HO•]	2.8
Sulfate radical [SO ₄ • ⁻]	2.5–3.1
Ozone [O ₃]	2.1
Persulfate [S ₂ O ₈ ²⁻]	2.1
Peroxymonosulfate [HSO ₅ ⁻]	1.8
Hydrogen peroxide [H ₂ O ₂]	1.8
Permanganate [MnO ₄ ⁻]	1.7
Chlorine dioxide [ClO ₂]	1.5



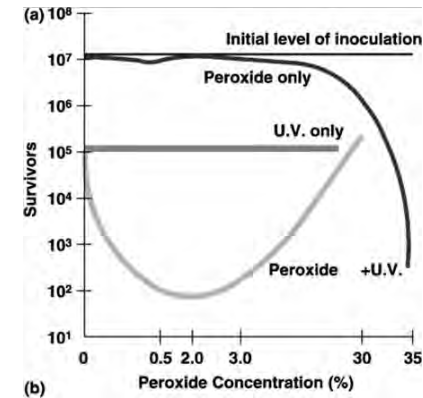
History of the Hydroxyl-radical Process



Henry Fenton
 $H_2O_2 + F(II)$
 Fenton Reagent



Advanced Oxidation Process
 Wastewater Treatment
 $UV + H_2O_2$



Elopak
 Carton Sterilization
 $UV + H_2O_2$ vapor



Hydroxyl Radical Process
 Fresh Produce
 Decontamination
 $UV + H_2O_2 + O_3$

1892



1979

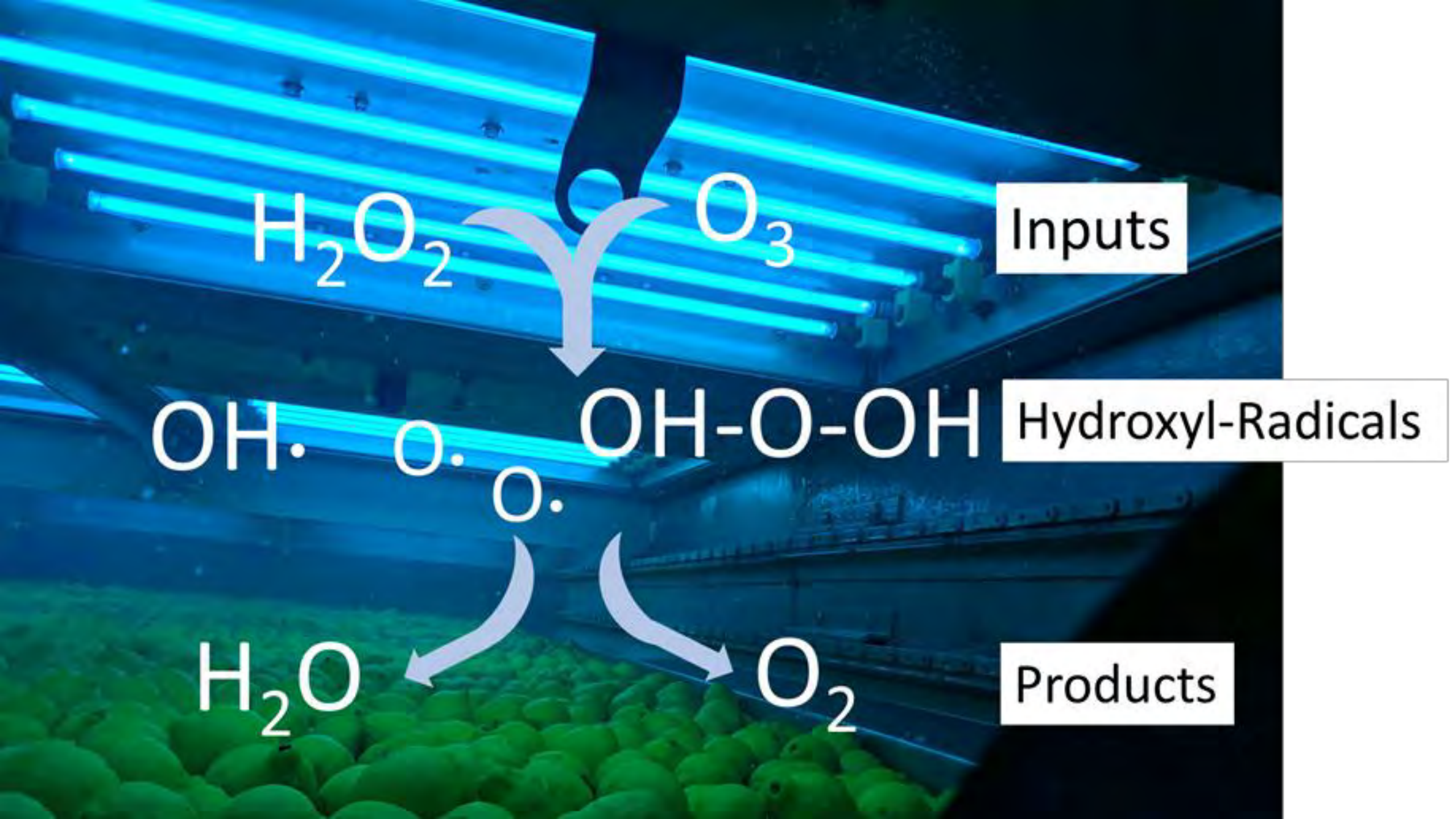


1983



2016





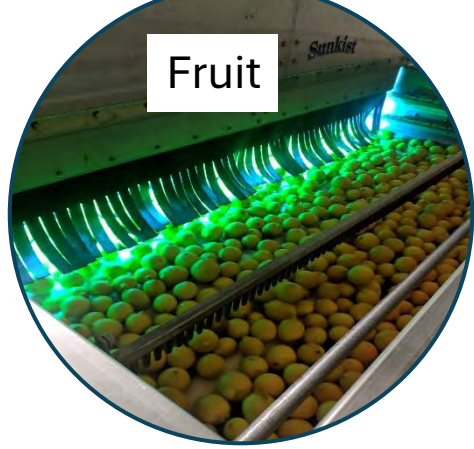
Inputs



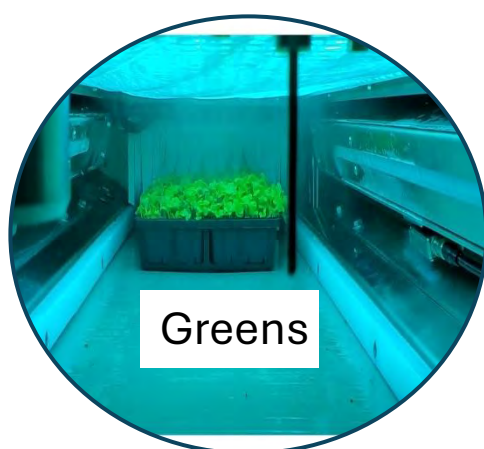
Hydroxyl-Radicals



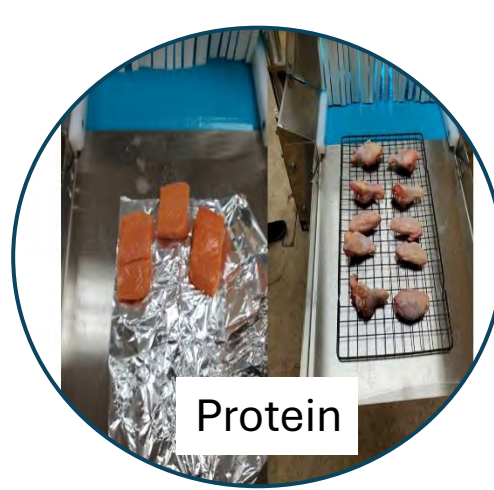
Products



Fruit



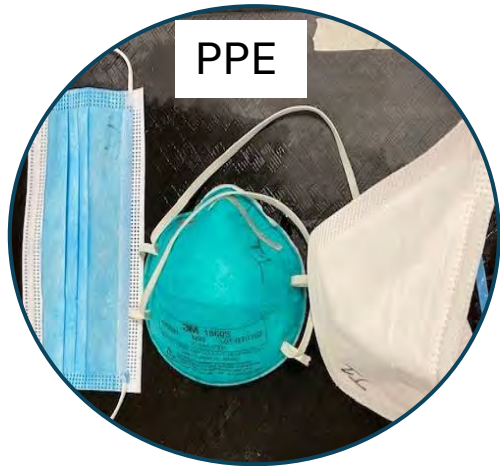
Greens



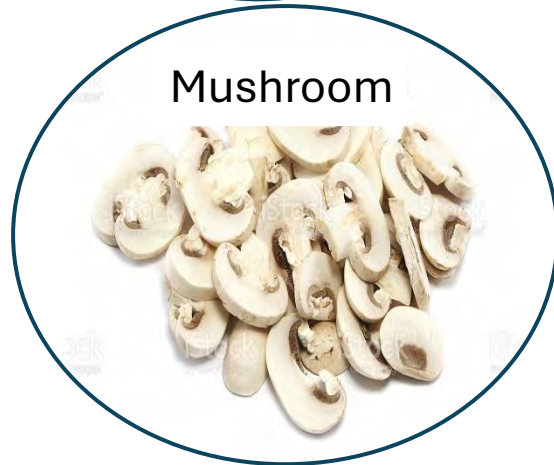
Protein



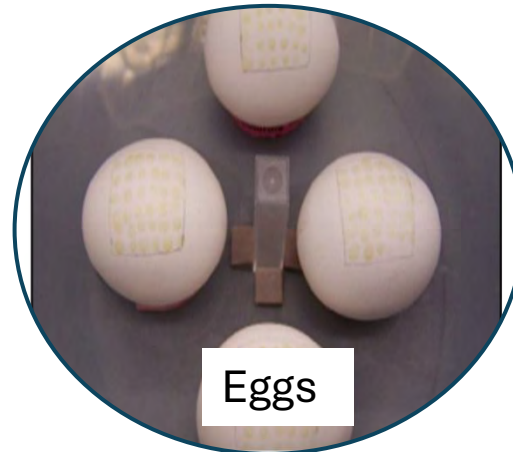
Leafy Greens



PPE



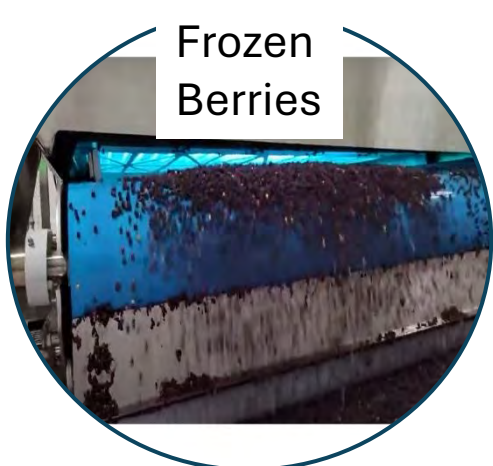
Mushroom



Eggs



Vine
s



Frozen
Berries



Nuts & LMF



Bags

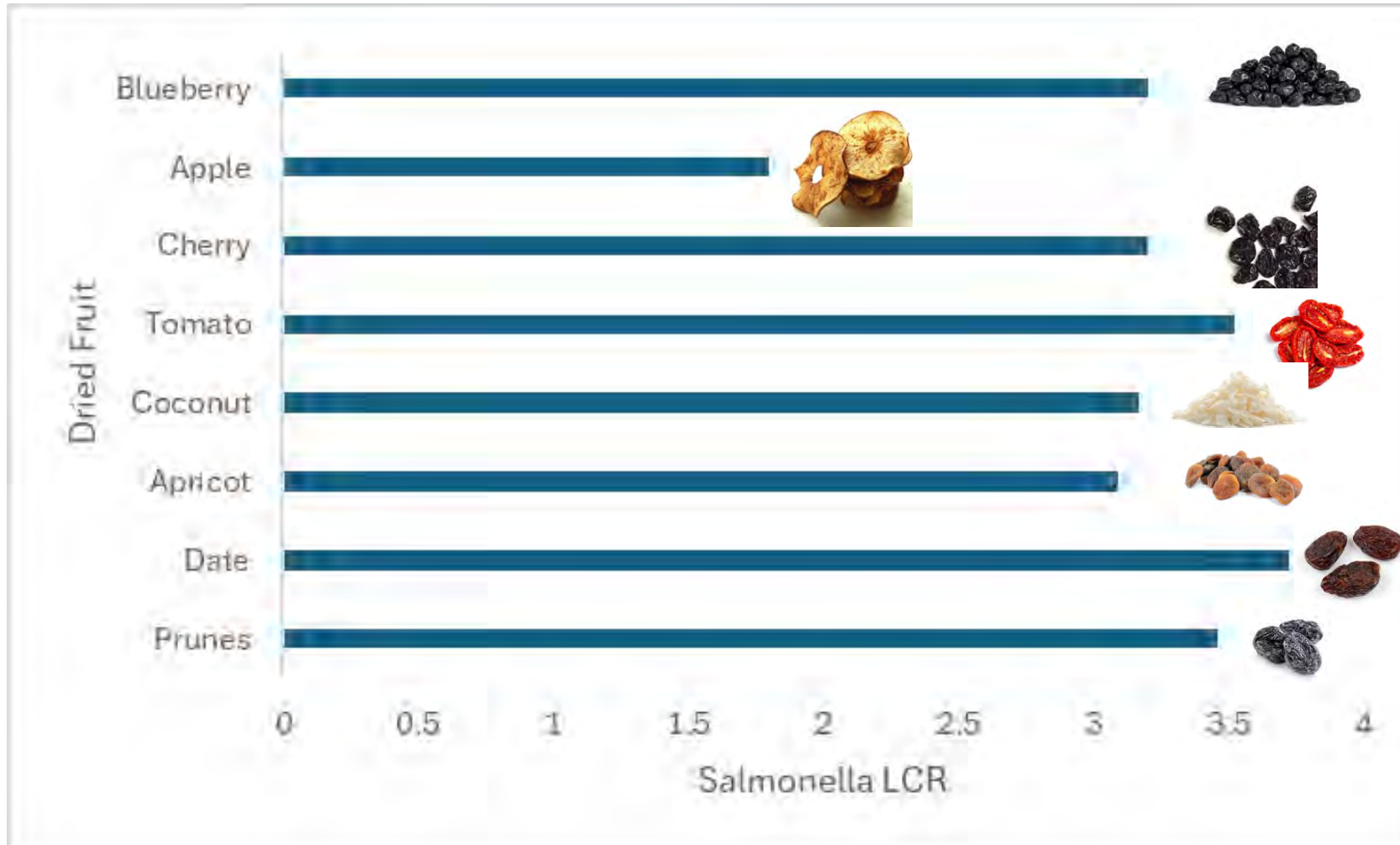


Crates

Gas Phase Hydroxyl-Radical Process

- Combination of hydrogen peroxide mist, ozone gas and UV-C
- Continuous, minimum water, process
- No residues or change in sensory
- Effective in pathogen reduction

Hydroxyl Radical Process: Dried Fruit



Post-AOP Treatment



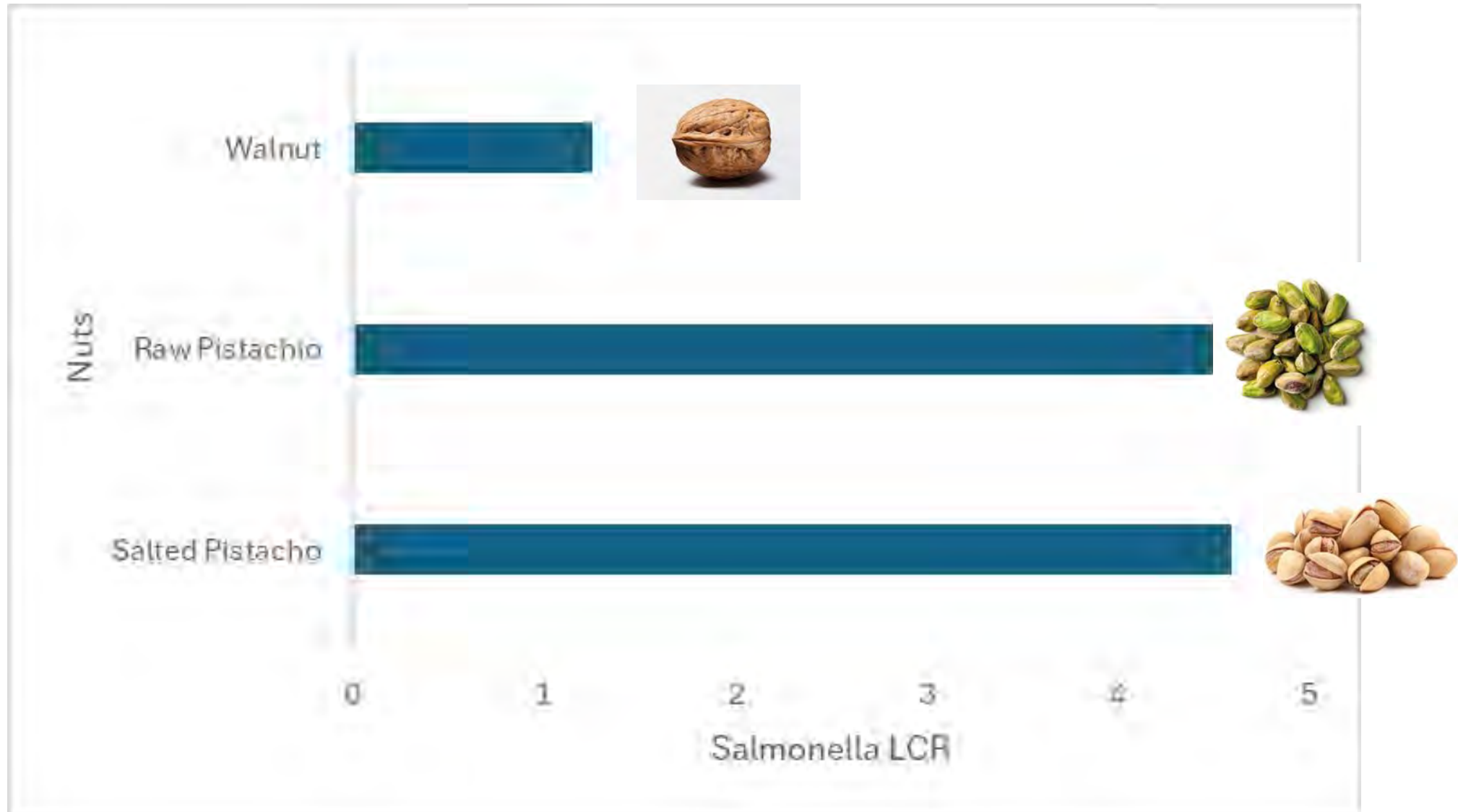
Prunes



Sun Dried Tomatoes

Dried Apricots

Hydroxyl Radical Process: Nuts

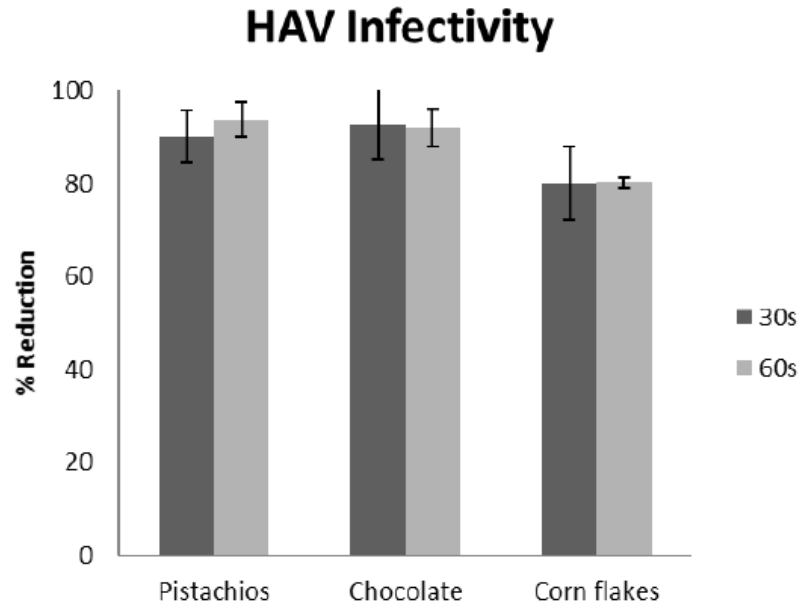


- Food safety of low moisture foods
- Dr Neda Nasheri (Health Canada)
- Inactivation of feline calicivirus (norovirus) and hepatitis A
- Dried nuts, chocolate, cornflakes

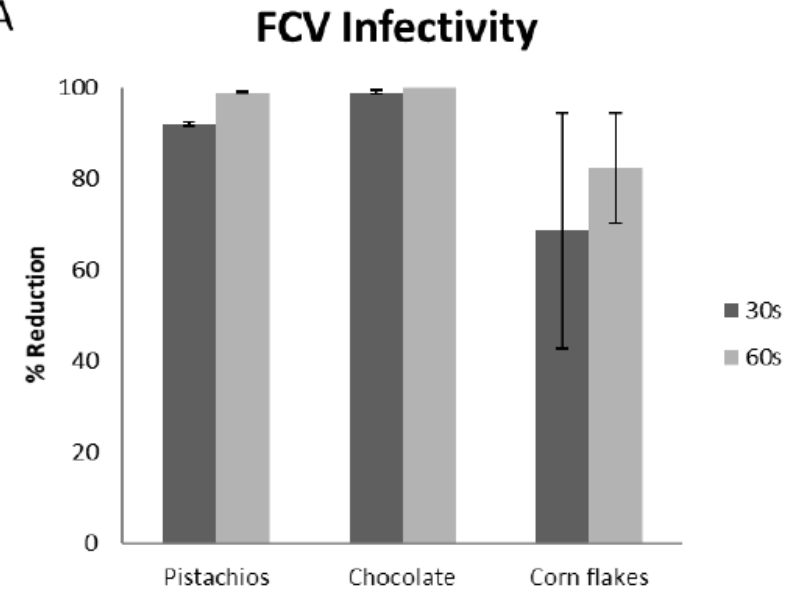


Infectivity Assay

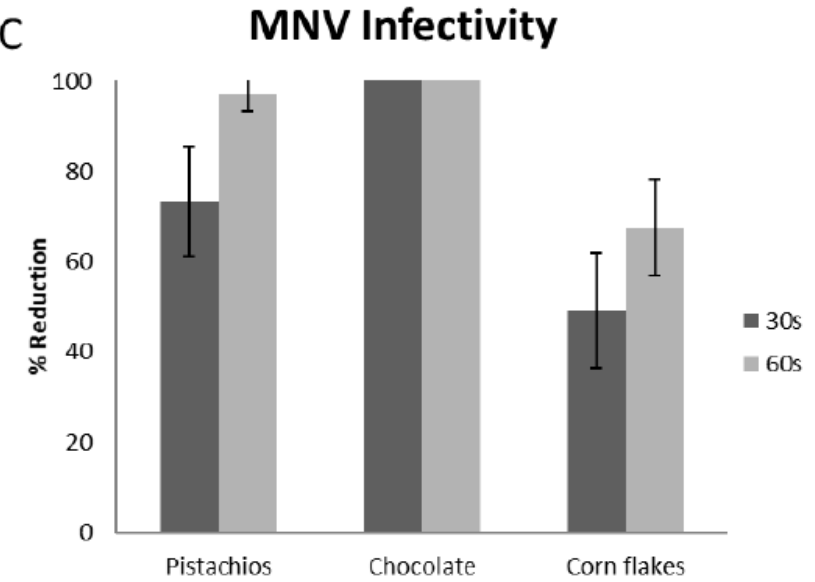
E



A

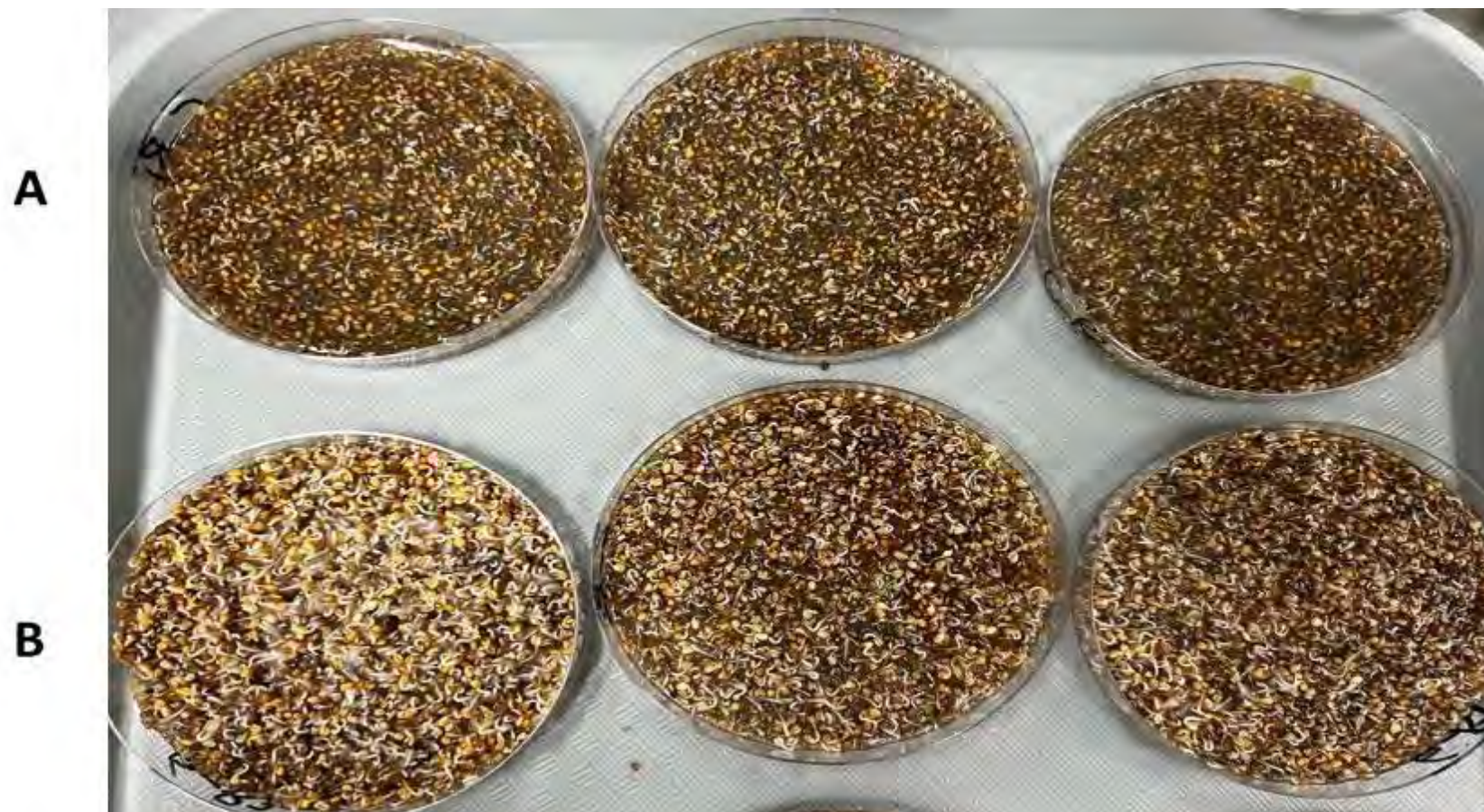


C

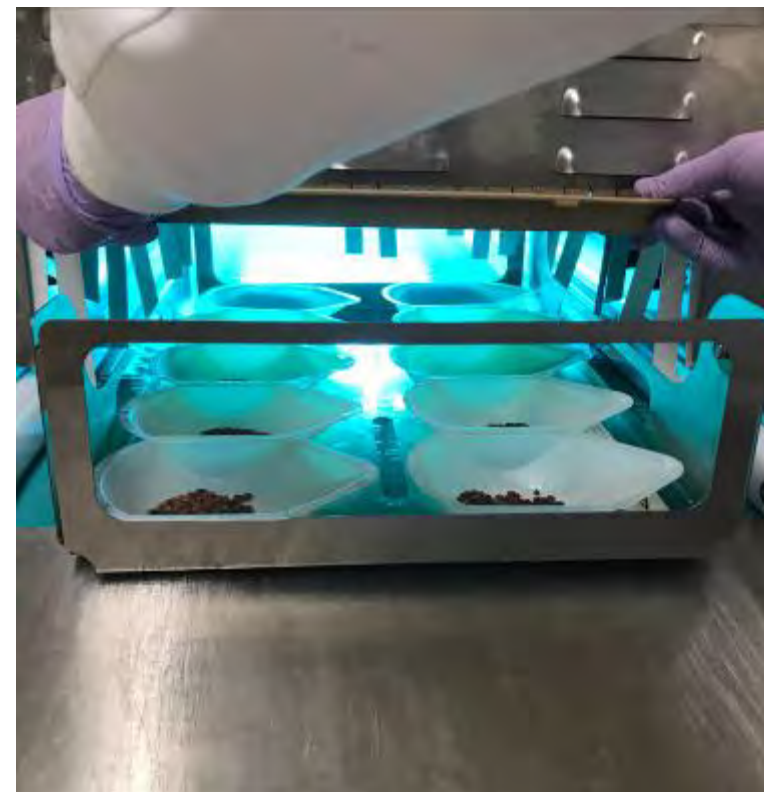




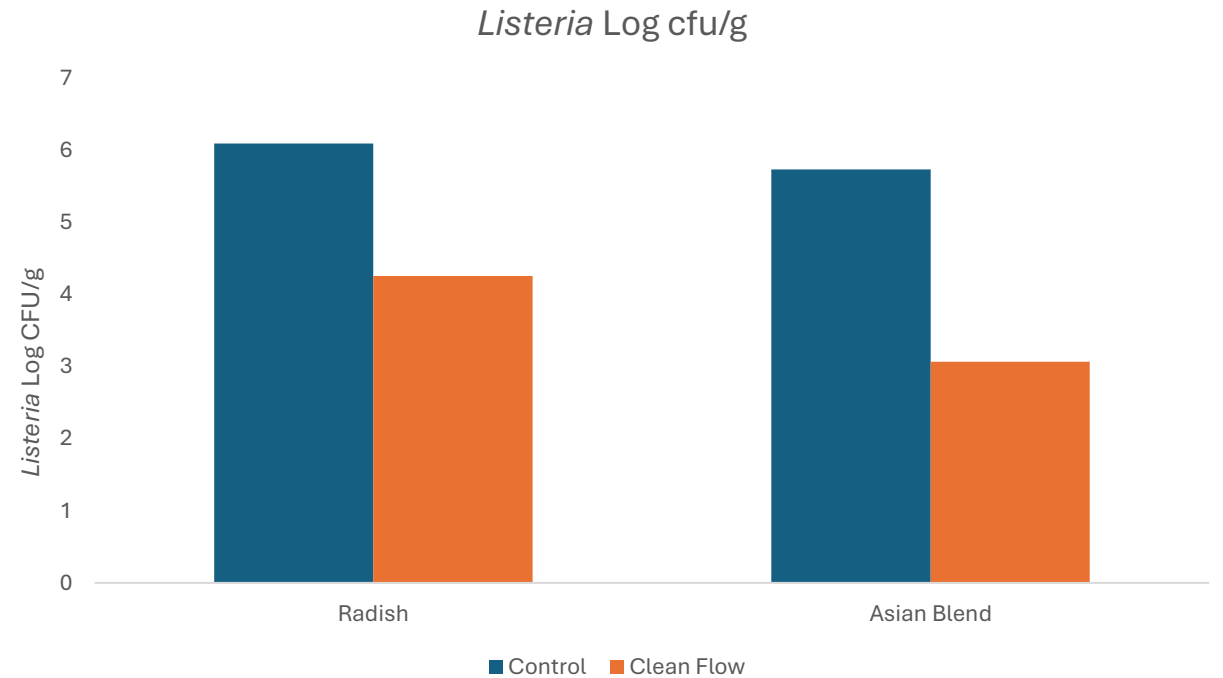
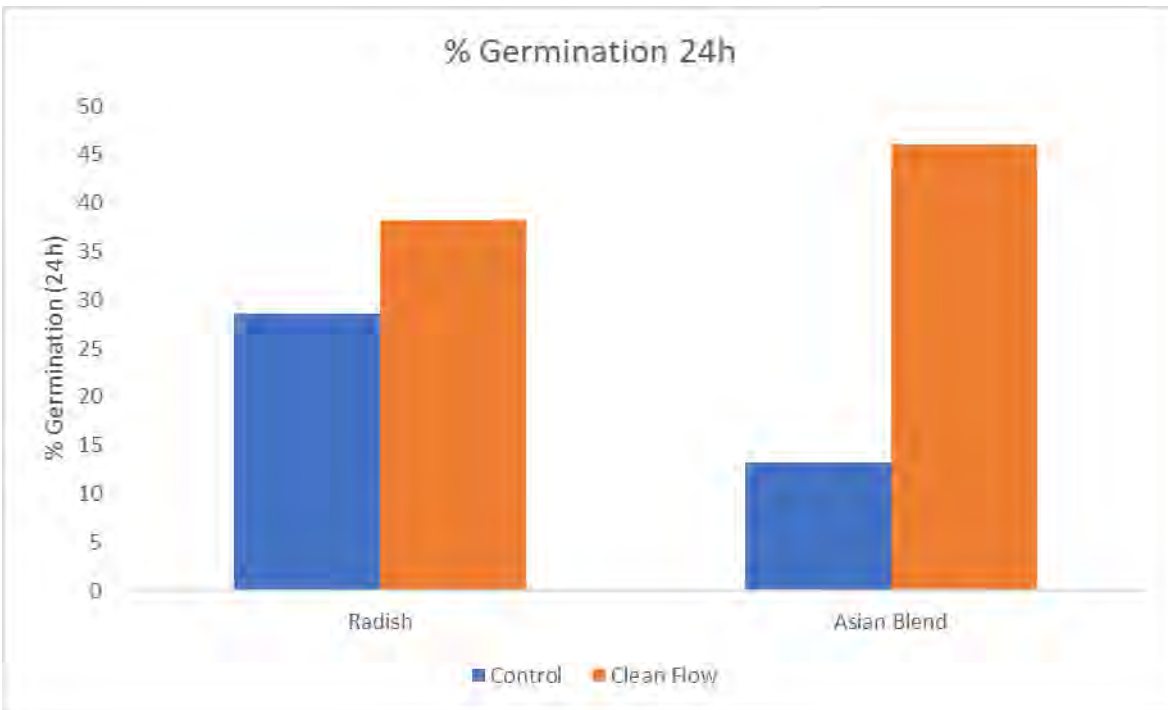
Control germinated seeds (A) and Activated Water 3 treated germinated seeds (B).



Germination of Arugula seeds after 48h, A: non-treated seeds, B: Clean Flow.



Hydroxyl-Radical Treated Seeds



Kibble

Operating parameters

3% hydrogen peroxide

30 ml/min

UV-C 226 mJ/cm²

30s treatment time

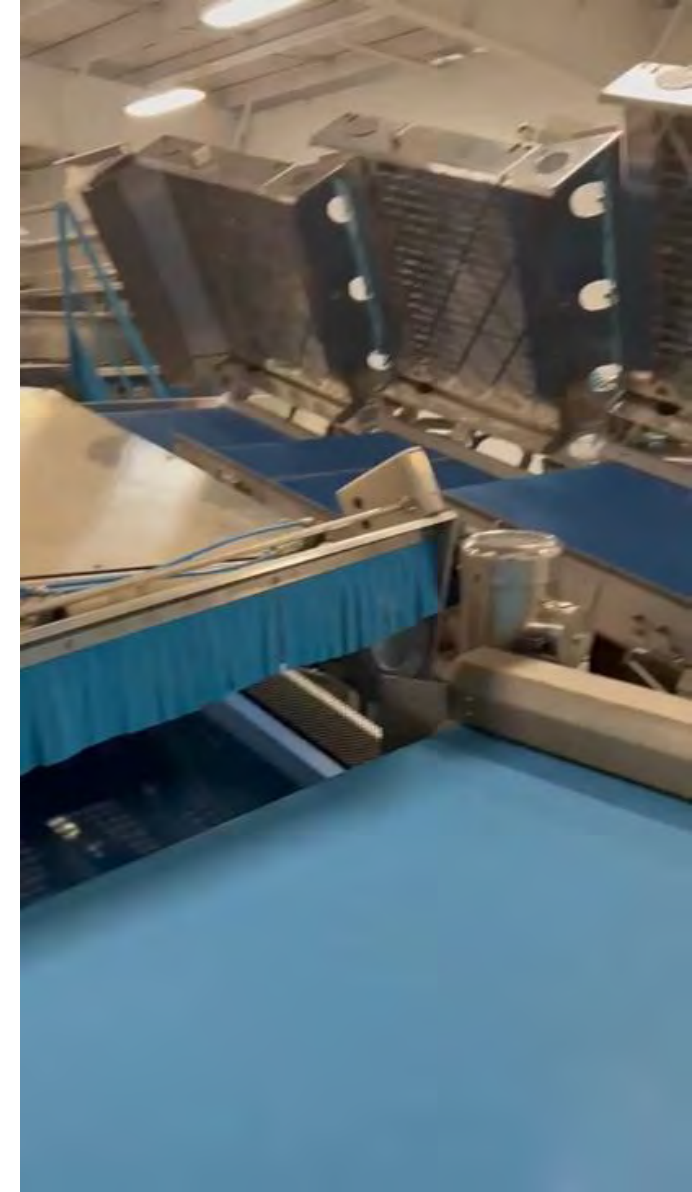
Salmonella: 1.04 LCR



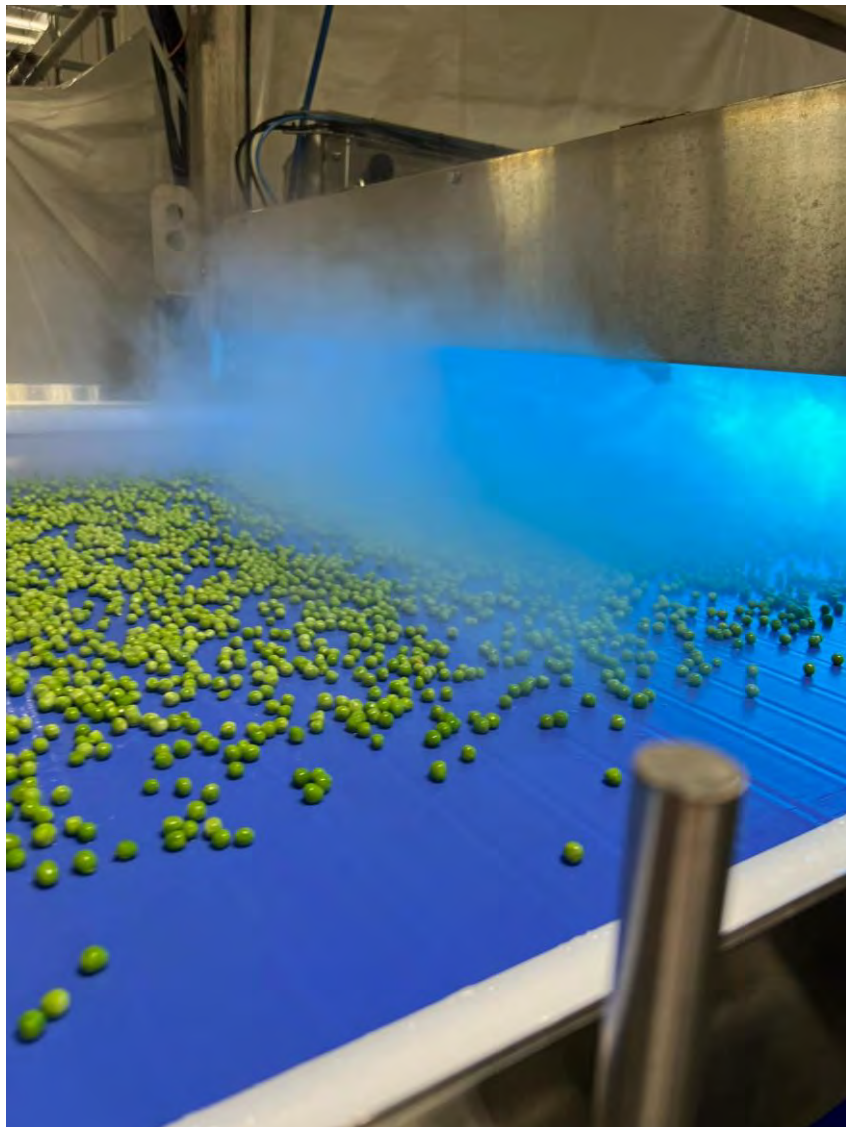




Commercial Units



Frozen Vegetables



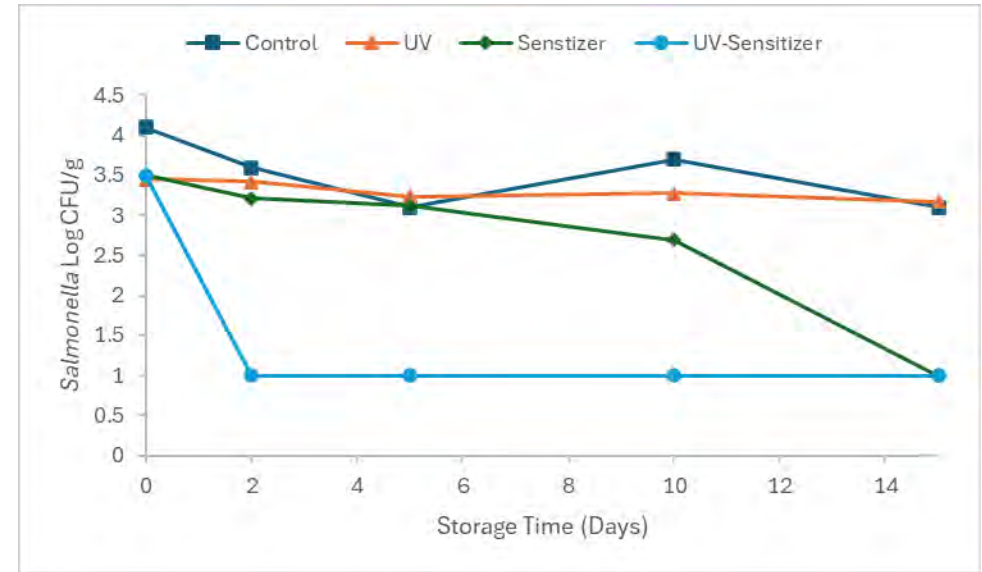
Decontamination of Shelled Eggs



Control of *Salmonella* in powders

Control of *Salmonella* in Flour

- Photosensitizer TY240
- Decrease in *Salmonella* over time
- No negative effect on flour functionality
- OMAFA 2025 - 2027

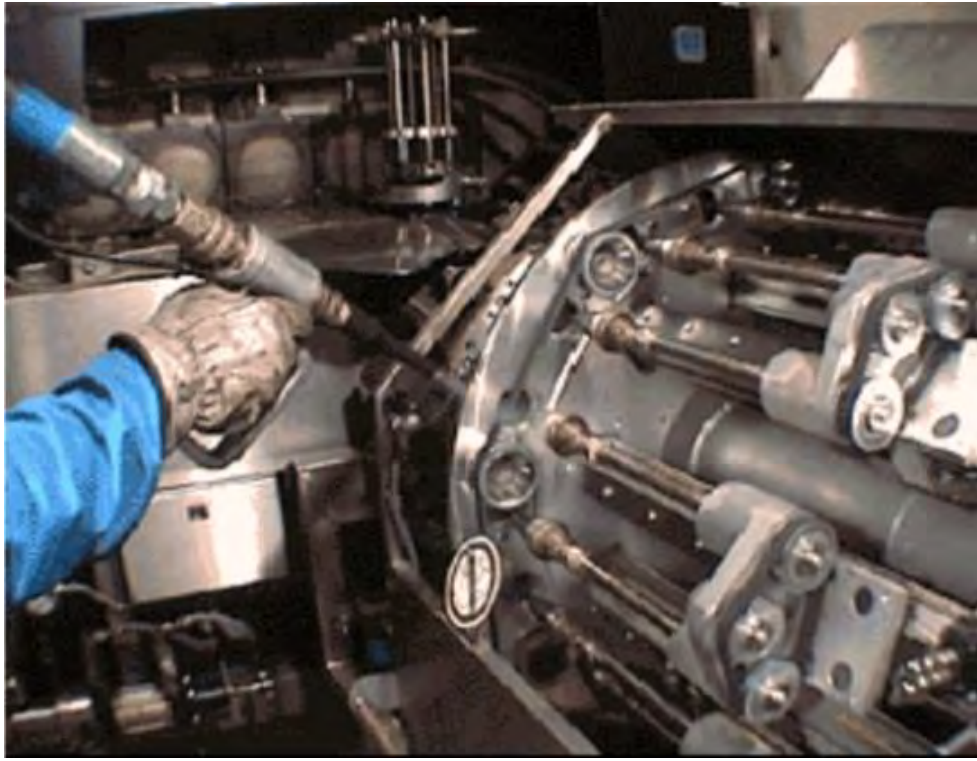


Sanitation

Dry Cleaning

- Pump hot oil: Not totally effective against *Salmonella*
- Cleaning equipment designated to the area
- Vacuum cleaners
- Alcohol based sanitizers
- Dry ice
- Compressed air to dislodge dust
- Hydroxyl-radical process (Far-UV: Hydrogen peroxide)





Conclusions

- LMFs are stable but can enhance the persistence of pathogens.
- Significance of dormancy still needs to be assessed
- Prevention through maintenance and sanitation
- Risk management options
 - Thermal – needs to be validated on a product basis
 - Non-thermal – promising but requires scaling
- Hydroxyl-radical process shows potential for risk-management throughout the chain

Research Team

- Dr Mahdiyeh Hasani
- Vanessa Camacho
- Sapphire Aberdeen
- Fan Wu
- Cristina Chaippe
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Low Moisture Food Safety

Focus on Dairy Powders & Infant Formula

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Webinar Agenda

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Why Dairy Products Demand Heightened Vigilance

Examples of dairy LMF products: whole milk powder, skim milk powder, whey powder, lactose, infant formula, dry dairy blends

Vulnerable Population

- Neonates and infants lack mature immune systems; case fatality rates for Cronobacter neonatal meningitis reach 40–80%
- Elderly individuals frequently use dairy products as supplements

Sole Nutrition Source

- Infant formula may be the only food source for weeks to months — daily, repeated exposure
- Protein drink supplements for elderly are key nutrition source in hospital settings

Preparation/Reconstitution

- Dairy powders might not be further processed
- WHO recommends 70°C water for reconstitution of infant formula, but compliance is imperfect in home and clinical settings

Distribution

- Single contaminated lot distributed across multiple states/countries before detection
- Undiversified production

Potential Pathogen Resistance

- Low a_w creates a "hostile but not lethal" environment — pathogens enter a stressed, desiccation-tolerant state
- Thermal resistance of pathogens increases dramatically at low a_w (D-values can be 10–100× higher)

Perception & Trust

- Consumers expect dairy powders and supplements to be RTE
- Formula contamination events cause enormous public trust damage and long-lasting demand shifts

Contamination Sources & Entry Points

How pathogens find their way into dry dairy systems

Contamination Sources: Raw Materials & Processing

- RAW MILK and FARM ENVIRONMENT: Mastitis-associated *Staphylococcus aureus*; *Salmonella*, *Listeria monocytogenes*, and many other pathogens from teat and milking environment
- INCOMING INGREDIENTS: Carbohydrates, vitamins, minerals, emulsifiers — major post-process addition risk for infant formula
- WATER QUALITY: Water used for pre-spray drying heat treatment; inadequate treatment can introduce *L. monocytogenes* and coliforms
- AIR HANDLING: Air drawn into spray dryer inlets — inadequate HEPA filtration introduces environmental *Salmonella*
- POST-DRYING ZONE: Fluid bed dryers, powder conveyors, sifters (watch out for moisture)
- STRUCTURAL HARBORAGE SITES: Expansion joints, hollow frames, cable trays, crevices in floors/walls/ceilings
- CONDENSATION: Temperature differentials cause condensation on equipment surfaces
- MAINTENANCE ACTIVITIES: People and equipment repairs can introduce environmental pathogens
- INSECTS & PESTS: Rodents and insects can track in *Salmonella* and other pathogens during storage
- CROSS-CONTAMINATION: Shared packaging lines, weighing equipment, or scoops between different product streams

Key Pathogens of Concern

Organisms with documented relevance to low-moisture dairy

Pathogens of Concern in Low-Moisture Dairy

Pathogen	Key Products	Min. Infective Dose	Desiccation Tolerance	Special Concern
<i>Salmonella</i> spp.	Milk powder, WPC, infant formula	<100 CFU (LMF context)	Very High — months to years in dry powder	Thermal resistance ↑ at low a_w
<i>Cronobacter sakazakii</i>	Infant formula (primary)	<1 CFU (neonates)	High — survives in dry environments	40–80% fatality in neonatal meningitis
<i>Listeria monocytogenes</i>	Dairy powders (rare endpoint)	Varies; possibly very low for susceptible populations	Moderate — less robust than Salmonella	Biofilm formation in wet niches
<i>Staphylococcus aureus</i>	Reconstituted concentrates	Toxin: 100–200 ng ingested	Moderate; heat-stable enterotoxins persist	Toxin survives processing of organism
<i>Bacillus cereus</i>	Milk powder, infant formula	10 ⁵ –10 ⁸ CFU/g (emetic)	Spores highly resistant	Spore germination upon reconstitution
<i>Enterobacteriaceae</i>	Spray-dried dairy	N/A (indicator organism)	Moderate	Indicator of post-process contamination
<i>Clostridium botulinum</i>	Environmental contamination can affect any product, but infant formula has been implicated	Low infectious dose for infant botulism	Spores highly resistant	No competition in infant gut <small>IAFP Low Moisture Dairy Webinar</small>

Salmonella in Low-Moisture Dairy: Deep Dive

- Over 2,500 serovars; different serovars implicated in dairy powder events over the years
- Unique thermal resistance: $D_{70^{\circ}\text{C}}$ in dry milk can exceed 30 min (vs. seconds in high-moisture systems)
- Water activity drives resistance
- Can survive for years in sealed powder containers stored at ambient temperature (documented 4+ years)
- Potentially low infectious dose in LMF (<10-100 CFU; fat-mediated stomach acid protection, stress cross-protection, low immunocompetency in consumer)
- Environmental persistence: forms microcolonies in dust, equipment crevices, and on stainless steel surfaces
- Whole genome sequencing (WGS) now routinely links environmental and clinical isolates — crucial for outbreak attribution

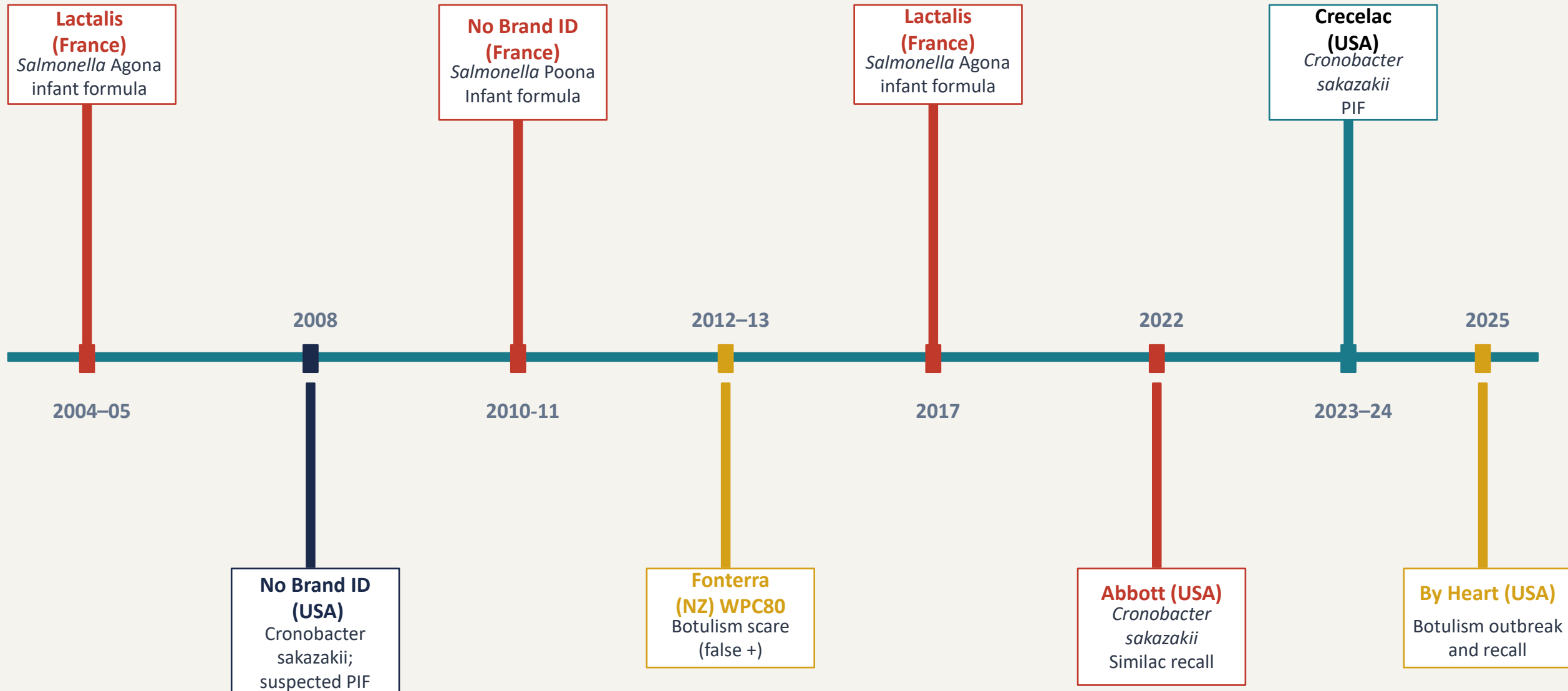
Cronobacter sakazakii: The Infant Formula Pathogen

- Gram-negative, motile *Enterobacteriaceae*; ubiquitous environmental organism — soil, water, plant material, insects
 - Genus *Cronobacter* includes 7 species; *C. sakazakii* is currently most relevant
- Clinical syndromes: neonatal meningitis, necrotizing enterocolitis, bacteremia — case fatality 40–80% for meningitis
- Desiccation tolerance: accumulates osmolytes (betaine, ectoine), robust trehalose-dependent stress response
- Survives months to years in spray-dried powder at $a_w < 0.2$; more tolerant than most *Enterobacteriaceae*
- Adhesins enable attachment to stainless steel, silicone, and polypropylene surfaces
- No zero-tolerance standard in U.S. finished product until 2023 FDA rule; Codex has strict limits for formula use in neonates
- Warm reconstitution (WHO: 70°C) critical kill step — not always followed in NICU or home settings

Notable Outbreaks & Recalls

2004–2024: Twenty Years of Hard Lessons

Major Outbreaks & Recalls: 2004–2025 Timeline



Case Study: Lactalis Infant Formula Recall (France, 2017–2018)

Scale

38 confirmed infant *Salmonella* Agona cases; recall encompassed ~12 million boxes; products distributed to 83 countries

Persistence

WGS linked isolates to a strain present in the facility since at least 2005 — 12+ years of environmental persistence

Regulatory Response

France mandated enhanced EMP requirements; EU-wide review of dairy powder production controls; Codex discussions intensified

Root Cause

Contaminated spray dryer tower at Craon facility; roof repair work **introduced water** and *Salmonella* into post-drying zone

Failures Identified

Inadequate environmental monitoring; failure to act on prior positive results; distribution continuing after initial alert

Key Lesson

A single contaminated niche in a post-drying area can contaminate product intermittently for years; EMP must be robust and acted upon

Case Study: Abbott / Similac Recall (USA, 2022)

Scale

Four cases of *Cronobacter sakazakii* and *Salmonella* Newport in infants; two *Cronobacter* deaths reported
Voluntary recall of Similac, Alimentum, and EleCare powders; temporary closure of Sturgis, Michigan facility (~40% of U.S. infant formula — recall triggered a severe national formula shortage)

Persistence

???

Industry/Regulatory Response

Facility upgrades, enhanced sanitation, new EMP protocols; FDA consent decree; third-party audits; Congress passed the FORMULA Act; FDA committed to updating infant formula manufacturing regulations (21 CFR Part 106)

Root Cause

Unsanitary conditions; positive environmental *Cronobacter* isolates in the facility

Failures Identified

Inadequate corrective actions to prior findings; WGS could not definitively link environmental strains to clinical isolates — genomic investigation limitations highlighted

Key Lesson

Supply chain concentration risk + regulatory enforcement gaps = catastrophic public health and economic outcome

Persistence in the Processing Environment

Why pathogens become residents, not visitors

- **BIOFILM FORMATION:** Microorganisms form biofilms at wet/dry interfaces (e.g., drain lips, condensation zones), which are likely multispecies and can contain pathogens
- **DESICCATION PROTECTION:** Powder matrices encapsulate organisms in a fat-protein shell reducing desiccation stress — "cocoon effect"
- **HARBORAGE SITE ARCHITECTURE:** Hollow legs, expansion joints, corroded surfaces, scratched plastic — biofilm sanctuaries resistant to cleaning
- **PHYSIOLOGICAL ADAPTATION:** Repeated sub-lethal stress exposures select for stress-tolerant subpopulations; cross-protection between heat and desiccation
- **INSECT and PEST VECTORS:** Can set up residence for reoccurring contamination
- **AEROSOLIZATION & REDEPOSITION:** Dry powder containing organisms becomes airborne during production, settles on surfaces, and re-enters product stream
- **NICHE-TO-NICHE TRANSFER:** Inadequate zone separation allows harborage organisms to transfer to product-contact surfaces during production
- **SEASONAL PATTERNS:** Some facilities show increased positivity in warm/humid months — condensation risk rises with external temperature swings

Harborage Site Identification: Where to Look

Spray Dryer

Inlet air ducts, cyclone dead legs, fluid bed discharge, fines return lines, inspection hatches

Powder Handling

Conveyor belt edges, sifter mesh frames, bag filter housings, elevator buckets, rotary valves

Packaging

Can seamer interiors, fill head crevices, dust collector filters, conveyor transfer points

Utilities / Structure

HVAC condensate pans, roof drainage paths, expansion joints in floors, hollow structural members

Wet-Dry Interfaces

Drains (especially those near dry zones), CIP return lines, condensate drip points under chilled pipes

Environmental Monitoring Programs

Designing EMPs that actually find problems

Designing an Effective EMP for Low-Moisture Dairy

- ZONE-BASED SAMPLING: Zone 1 (product contact) → Zone 2 (adjacent non-contact) → Zone 3 (near environment) → Zone 4 (far environment)
- INDICATOR ORGANISMS: Choose wisely based on implications of the location and product; negative results do not tell you anything about potential pathogen contamination
- TARGET PATHOGENS: *Salmonella* (all dry dairy); *Cronobacter* (infant formula, specialty powders); *Listeria* (where moisture niches exist)
- SAMPLE SITE SELECTION: Risk-based — prioritize harborage sites, wet-dry interfaces, post-drying zones, and post-kill-step areas
- SAMPLING FREQUENCY: Gradient from high frequency at Zone 1 to lower at Zone 4; intensify after maintenance, wet cleaning, or positives
- SAMPLE TIMING: During production (not just after sanitation) — catches organisms re-entering product zone
- SWAB TECHNIQUE: Adequate surface area (1,000 cm² composites for environmental), sterile technique, rapid transport to lab, aseptic sampling that avoids introducing moisture
- ACTION LEVELS: Predefined corrective action thresholds; indicator positives trigger investigational swabbing before pathogen testing

- REGULATORY EXPECTATION: FDA expects robust, documented EMPs as part of FSMA Preventive Controls compliance
- MAPPING POSITIVES: Maintain live facility maps showing location and recurrence of positives — patterns reveal harborage sites
- TIME-SERIES ANALYSIS: Track positive rates by zone and organism (indicators) over time — seasonal trends and post-maintenance spikes are signals
- CORRECTIVE ACTION TRACKING: Every positive must trigger a documented CA; confirm effectiveness with follow-up sampling
- WHOLE GENOME SEQUENCING: WGS of environmental isolates enables harborage site identification and cluster analysis over time
- HOLD-AND-TEST PROTOCOLS: Finished product from shifts with positive Zone 2/3 results should be held for additional testing
- INVESTIGATIONAL SAMPLING: Positive triggers expanded swabbing in affected zone with additional sites to identify source (50–100 or more depending on size of facility)
- SHARE FINDINGS INTERNALLY: Regular EMP review meetings with QA, operations, maintenance, and sanitation leadership

Cleaning, Sanitation, & Dry Cleaning

The unique challenge of keeping dry facilities clean

Dry Cleaning vs. Wet Cleaning: Knowing When to Use Each

Dry Cleaning (Preferred Default)

- Vacuuming with HEPA-filtered industrial vacuums
- Brushing/wiping with food-grade dry cloths
- Compressed air (*use cautiously and with discretion*) — directed away from product zones
- Dedicated color-coded dry tools per zone
- Electrostatic dusting on flat surfaces
- Inspection and physical removal of powder accumulations
- Immediate removal of powder spills to prevent moisture absorption

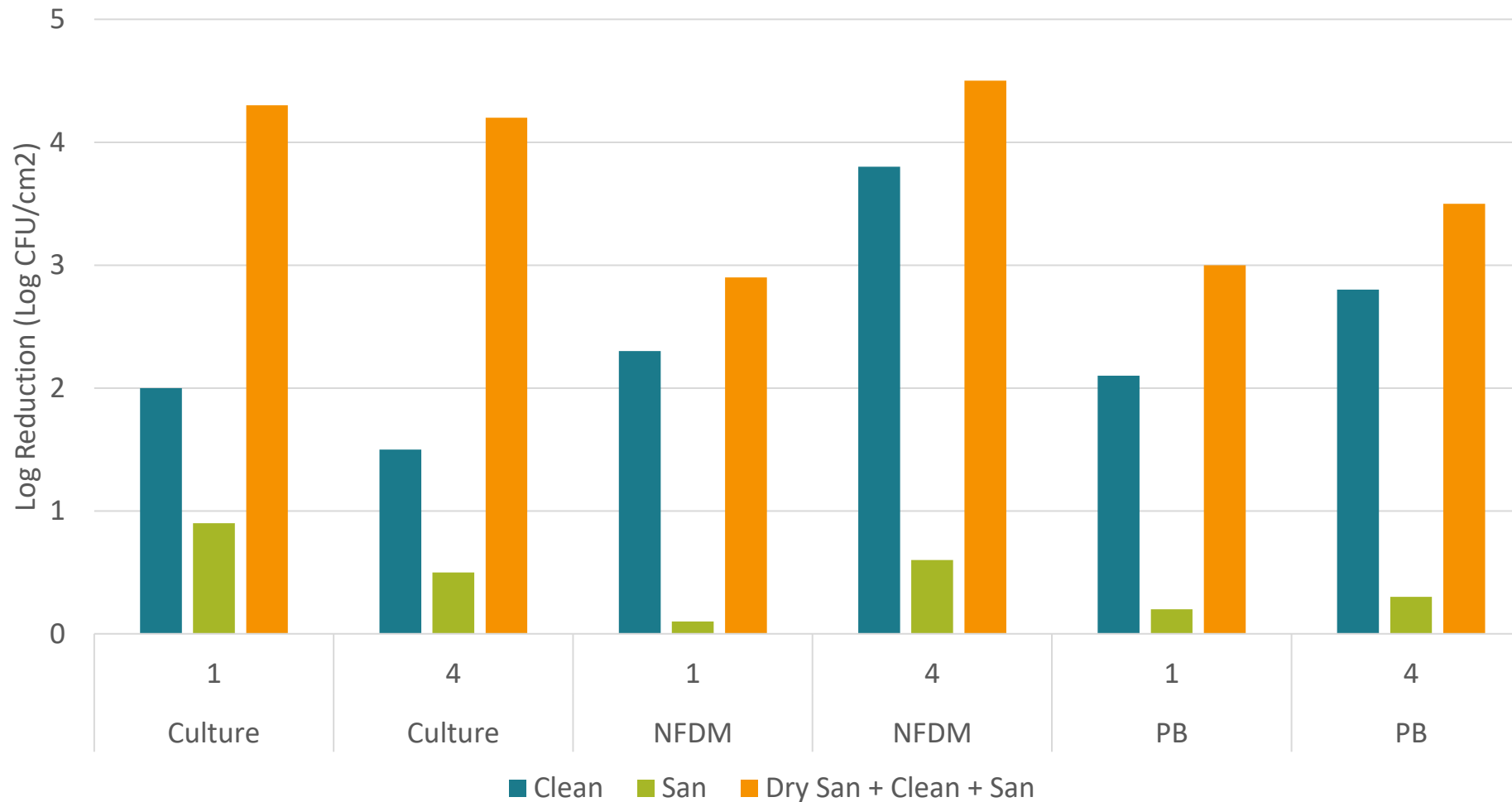
Wet Cleaning / CIP (Use With Extreme Care)

- Reserve for allergen changeovers and scheduled deep cleans
- Adequate dry-out period (24–72 hrs) before restart mandatory
- Validate dry-out using aw measurement and EMP re-sampling
- Wet cleaning of one zone at a time — never entire facility simultaneously
- CIP circuits must be fully separated from dry powder zones
- Monitor condensation points actively for 48 hrs post-wet clean
- Enhanced EMP sampling before return to production

- **EFFICACY CHALLENGE:** Most sanitizer efficacy data is generated in aqueous systems — not directly applicable to dry surfaces with powder residue
- **POWDER MATRIX INTERFERENCE:** Milk powder creates organic load that rapidly neutralizes quaternary ammonium and chlorine-based sanitizers
- **DRY SURFACE SANITATION:** Alcohol-based (70–80% ethanol/IPA) wipes effective for equipment surfaces in targeted applications; limited penetration into biofilms
- **GASEOUS DISINFECTION:** Chlorine dioxide gas and vaporized hydrogen peroxide (VHP) used for room-level disinfection in high-care powder facilities
- **OZONE:** Dry ozone fumigation studied for powder environments; limited penetration and material compatibility concerns
- **UV-C:** Effective for surface and air decontamination in supplemental roles; no penetration of powder matrix or shadowed areas
- **BIOFILM REMOVAL:** Pre-cleaning mechanical removal essential before sanitizer application — sanitizers cannot penetrate intact biofilms
- **VALIDATION REQUIREMENT:** All sanitation procedures in LMF environments must be validated under actual use conditions, including organic load

Research Findings

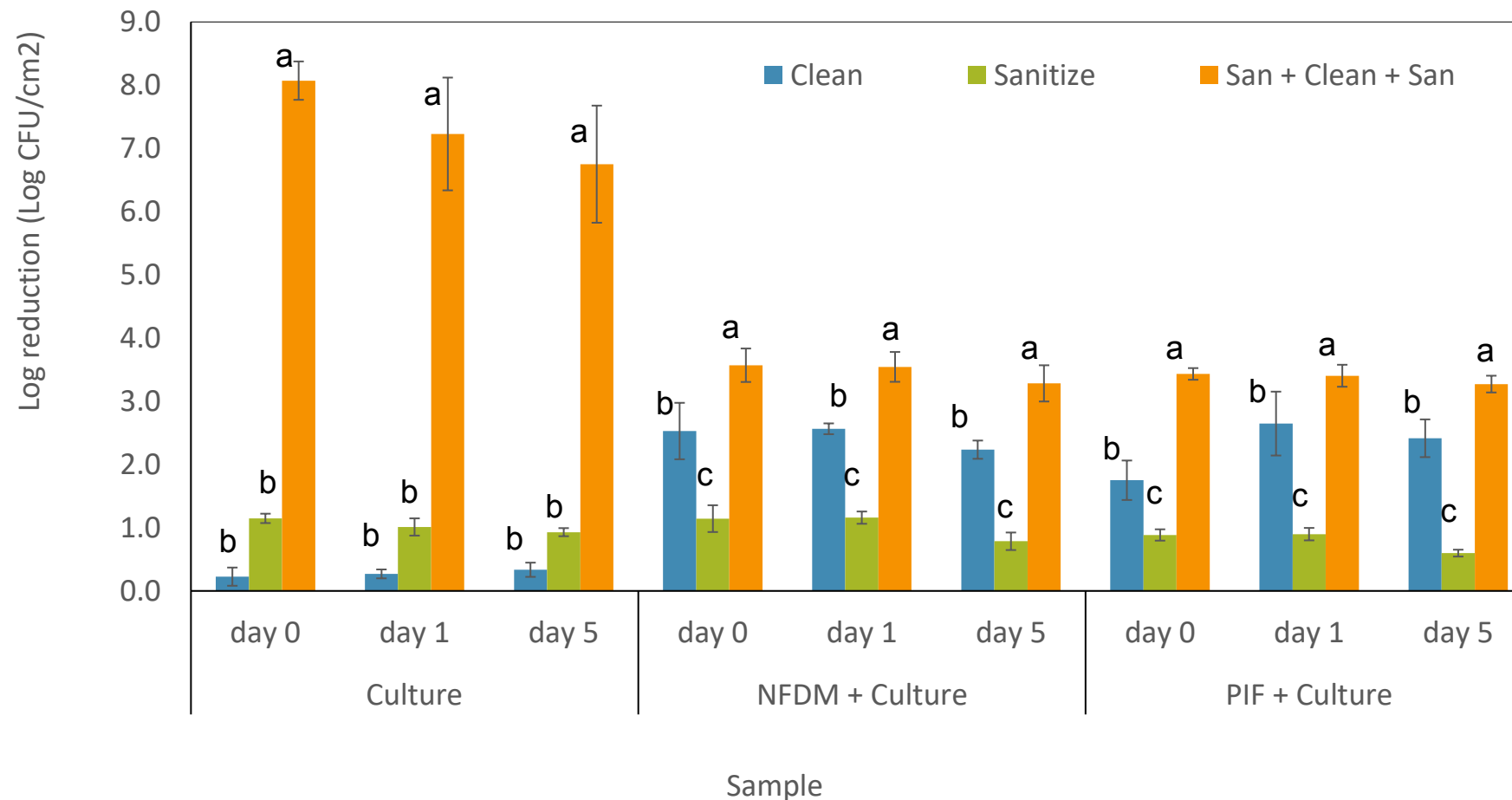
Effect of cleaning/sanitation treatments on *Salmonella* Tennessee (culture) and powdered infant formula (PIF) or nonfat dry milk (NFDM) slurries on stainless-steel coupons after 1 or 4 days of storage (30% RH).



Application of the dry sanitizer (isopropyl alcohol-based solution) to aid in cleaning step (scraping) made final sanitation step significantly more effective. Storage time made no difference. Matrix impacted treatment efficacy.

Research Findings

Effect of cleaning/sanitation treatments on *C. sakazakii* cocktail (culture) and powdered infant formula (PIF) or nonfat dry milk (NFDM) slurries on stainless-steel coupons after 0, 1, or 5 days of storage (30% RH).



Same trends observed, though exact values differed somewhat.

Risk Assessment & Prevention

Anticipating and addressing risks

- HAZARD ANALYSIS: Distinguish between **validated** process-kill steps (e.g., spray drying as CCP for heat-labile organisms) and post-process contamination hazards
 - SPRAY DRYING AS CCP: Outlet air temperature and residence time can be validated for target pathogen reduction — but drying does NOT sterilize
 - POST-PROCESS CONTAMINATION PREVENTION: Critical preventive control for dry dairy — environmental harborage elimination
- ALLERGEN CONTROLS: Allergen matrix requires dedicated preventive controls and validated clean-out procedures; make sure they don't introduce other issues
- ZONE SEGREGATION: Physical and procedural barriers between raw/pre-kill and post-kill zones are foundational preventive controls
- SUPPLIER VERIFICATION: Ingredients added post-drying (vitamins, minerals, enzymes) require robust supplier verification and review (don't just trust a COA)
- WATER ACTIVITY MANAGEMENT: a_w of finished product must be controlled and verified (don't forget storage conditions)
- RECALL PLANNING: Traceability systems that can isolate affected lots within 24 hours — critical given wide distribution of dairy powders

Quantitative Microbial Risk Assessment (QMRA): Probabilistic modeling of exposure and dose-response to estimate illness risk per serving

- Hazard identification → hazard characterization → exposure assessment → risk characterization
- PREDICTIVE MICROBIOLOGY: Growth/survival models (e.g., ComBase) adapted for low- a_w conditions to estimate fate during storage and distribution
- PREVALENCE AND CONTAMINATION: Must be explored before determining actual exposure likelihood (requires time and A LOT of sampling)
- DOSE-RESPONSE: Consideration of host and environmental factors, as well as variability, to determine likely infective dose (difficult with dairy powders with wide consumer base)
 - Account for consumer behavior (reconstitution temperature, hygiene, vulnerable populations)
- FOOD MATRIX EFFECTS: Fat content of dairy powder significantly increases *Salmonella* infectious risk vs. aqueous models — critical for model parameterization
- APPLICATIONS:
 - Comparison of interventions (better EMP vs. end-product testing vs. consumer warnings)
 - Set sampling plan stringency, lot acceptance criteria, and regulatory limits
 - Integrate WGS data from EM into assessments

Future Research Frontiers

Where science needs to go to keep pace with industry challenges

Priority Research Areas: Low Moisture Dairy Food Safety

Rapid Detection Methods

Validated rapid (same-shift) methods for environmental *Cronobacter* and *Salmonella* detection

Biofilm Biology in Dry Environments

Characterize biofilm formation at wet-dry interfaces; identify molecular targets for novel anti-biofilm interventions

Desiccation Tolerance Mechanisms

Systems biology of desiccation tolerance in *Cronobacter* and *Salmonella* — targets for attenuation or detection biomarkers

Novel Dry Sanitation Technologies

Cold plasma, electrostatic spraying of dry disinfectants, phage-based biocontrol validated for powder facility surfaces

Whole Genome Seq. for EMP

Standardized WGS-based attribution pipelines for routine EMP — distinguishing transient introductions from true harborage

QMRA Refinement

Better dose-response data at ultra-low doses; improved food matrix effect models for dairy fat systems

Key Takeaways

Turning knowledge into safer products

Key Takeaways

- 1 Low a_w does not kill pathogens — it makes them more resistant. Design food safety systems around survival, not death.
- 2 The processing environment IS the primary risk. Invest in harborage site elimination and robust, data-driven EMP programs.
- 3 Infant formula is a special case. Any positive *Cronobacter* finding demands immediate and exhaustive investigation.
- 4 Wet cleaning in dry facilities is a tool of last resort — always verify dryout and EMP before restarting production.
- 5 Sample widely and use WGS. Environmental genomics transforms EMP from counting positives to understanding persistence.
- 6 History repeats. Every major outbreak shared common themes: known positives ignored, inadequate corrective actions, siloed data.

Upcoming Food Safety Webinars (April – May 2026)

Date	Time (Eastern Time)	Webinar Title
Apr 30	11:00 AM – 12:00 PM	The Critical Role of Hygienic Engineering in Today's Food Production
Apr 30	2:00 PM – 3:30 PM	Intro to Gen-FS: An overview of the Genomics for Food and Feed Safety Collaboration
May 4	12:00 PM – 1:00 PM	Clostridium botulinum in Dairy: Risk, Control, and Prevention Strategies – A Live Expert Roundtable
May 20	12:30 PM – 1:30 PM	Neurodivergent Thinking in Food Safety: Implications for Practice, Performance, and Inclusion
May 28	1:00 PM – 2:00 PM	Using Data Trends to Improve Microbial Risk Detection in Food Safety Systems

This webinar is being recorded and will be available for access by **IAFP members** at www.foodprotection.org within one week.

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