# Emerging Non-chemical Disinfection and Disinfestation Processes for Food & Agriculture

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COEH Continuing Education Program
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# Outline

I. Food Safety & Environmental Health.
II. Radiofrequency (RF) Power.
   - Introduction & Rationale of RF Technology.
   - Principle of RF Technology.
   - RF Disinfection & Disinfestation Mechanisms.
   - RF Equipment Design.
   - Results.
   - Conclusions & Future Directions.
III. Metabolic Stress Disinfection & Disinfestation (MSDD).
   - MSDD Effects & System Design.
   - MSDD Operation.
   - Results.
   - Conclusions & Future Directions.

# Food Safety & Environmental Health

- The presence of pathogens and insects in foods and related products poses a threat to human & environmental safety.
- Current techniques (i.e. chemical pesticides and fumigants, irradiation) are either invasive or resisted by consumers and strongly regulated or being phased out.
- New non-invasive (physical), residue-free and environmental friendlier processes are thus needed.
- RF and MSDD are new non-chemical alternatives being developed at UC Davis.



# Radiofrequency Power

- **Radiofrequency (RF) power** is an **electricity-based technique** that uses **oscillating electric fields** to add energy to different materials. Energy is absorbed **selectively and rapidly by dielectric or conductive biological pests and less efficiently by host materials** causing **combined thermal and electric effects** in pests leading to their biological inactivation. RF photons are non-ionizing and have very small amounts of energy ($10^{-9}$ to $10^{-6}$ eV) and are delivered with **0.3 to 20 MHz** frequencies.
- At UC Davis, novel applications have been developed since 1998, patented (USP # 6,638,475) in 2004, and licensed for worldwide commercial use in 2008 (see www.rfbiocidics.com).
- RF power is being introduced as an alternative process to chemical pesticides or to biological controls for disinfection and/or disinfestation applications including conventional and organic food and agricultural products.

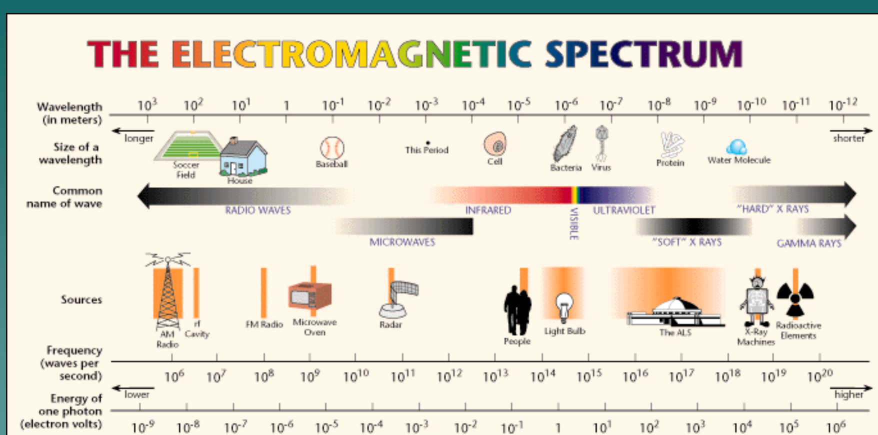
## Metabolic Stress Disinfection & Disinfestation (MSDD)*. - General and Operational Concepts

- MSDD is a cyclic process that combines physical and chemical effects and is applied for a certain time (2 – 6 h) in closed chambers. It is applicable in boxes and multiple pallet levels.
- Physical Phase modifies the gaseous environ to induce anoxia and stresses such as:
  - (1) respiratory, anatomical, and functional in insects/mites
  - (2) respiratory and functional in microbes.
- Chemical Phase: using innocuous, transient (removable) volatile chemicals (single or mixed) that leave no detectable residues but accelerate metabolic stress and add a topical disinfectant action.

*** US patent applied**



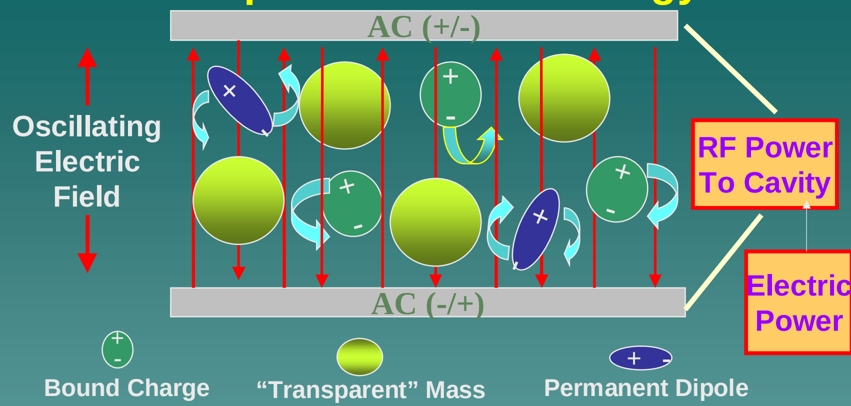
## Introduction & Rationale of RF Power




(From http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html)

- Radiofrequency: electromagnetic (EM) waves from 3 kHz (wavelength: $\lambda = 10^5$ m) to 300 MHz ($\lambda = 1$ m).
- Penetrates deeply into most biological materials.
- Interacts with dipole molecules to generate heat.

# Principles of RF Technology




- RF waves consist of electric & magnetic fields, but only E-field interacts with charges in biological (non-magnetic) materials.
- Oscillating E-field polarizes and reorients bound charges & permanent dipoles; and generates heat from friction.
- E-field can also form a conducting path with ions, and generate heat by conductive (resistance) heating.



# Principle of RF Technology

- The average power absorption:

$$P_{th} = 2\pi\varepsilon_0 \varepsilon''_{eff} f E_{rms}^2$$

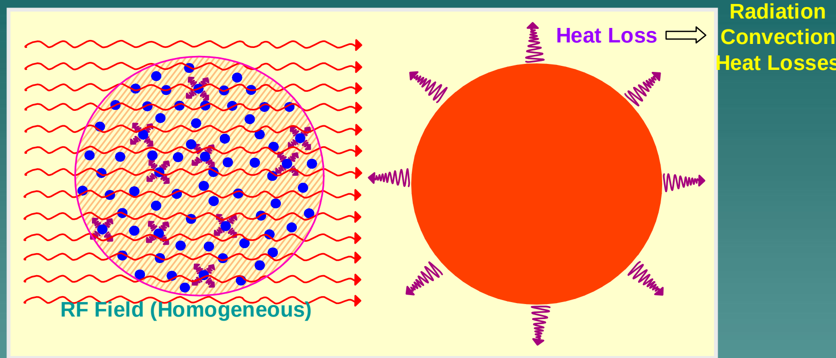
*$P_{th}$: thermal power per unit volume ($W/m^3$)*
*f: frequency of oscillating E-field (Hz)*
*$E_{rms}$: root-mean-square E-field (V/m)*

Thermal power reaches a maximum at the “resonant frequency” for a treated commodity and allows high (>80%) overall energy-use efficiency (wall power-to-RF and RF-to-thermal).

Lagunas-Solar, Zeng & Essert (Inventors): US Patent No. 6,638,475.

# Principles of RF Technology

- RF heating is: Volumetric (internal) heating.



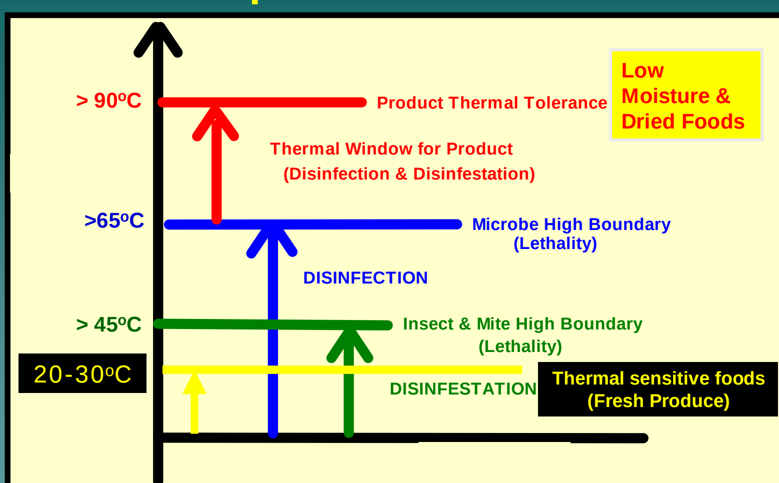

- Temperature distribution (one dimension):

$$\frac{\partial T}{\partial t} = a_T \frac{\partial T}{\partial x} + \frac{\delta P}{\rho c_p}$$

$a_T$: thermal diffusivity ($m^2/s$)
P: localized power density ($w/m^3$)
r: density of the material ($kg/m^3$)
$c_p$: specific heat capacity ($J/kg.^{O}C$)



# Concept of Thermal Window



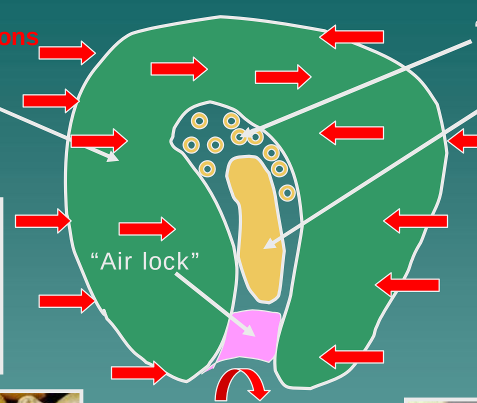

Thermal windows allow the use of RF power as a controlled thermal process to disinfect and/or disinfest without changes in host food commodity.

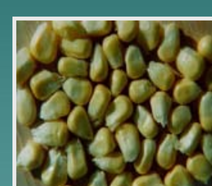
# RF Power and Nut & Grain Products

- Nut and grain products are low-moisture foods naturally affected by infective organisms as well as insect pests. Consumption has increased because of consumer preferences for high nutrition foods.
- With nut and grain products inactivation of human pathogens and insect pests is achieved simultaneously by combining thermal and electric field effects at levels below thresholds that cause changes in sensory and nutritional properties.
- Thermal inactivation in the 70 to 90°C (1-3 min) is sufficient to provide > 5 $log_{10}$ reduction levels for *Salmonella spp*., *E. coli* O157:H7 and many other human pathogens of concern.
- All biological cycles of insect pests are heated rapidly (45 to 60°C; 1-3 min) inducing lethal effects but are well tolerated by low-moisture foods.



# RF Disinfestation of Nut and Grain Products



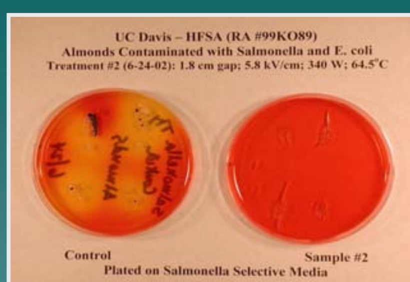
## RF Disinfection of Almonds (~12 kg/batch). UC Davis RF Research Prototype

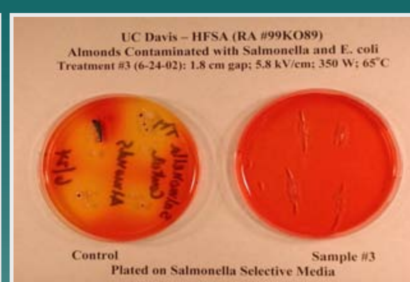
Temperature monitoring with fiber optics in four (4) locations.

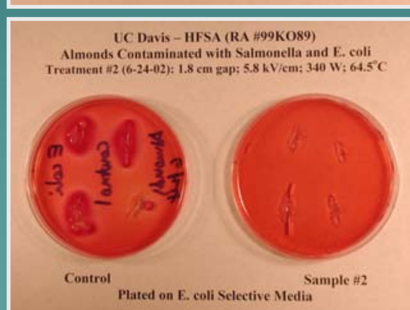
Range of temperature ± 3°C for 1.5 kW power at 11.5 MHz (2 min.)



## RF Disinfection of Inoculated Fresh Almonds (~1x10$^7$ cfu/mL)



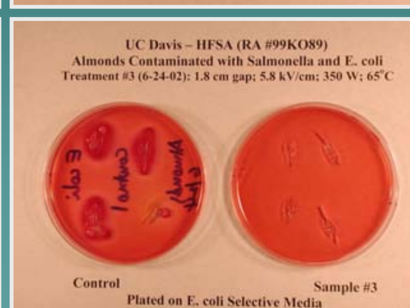



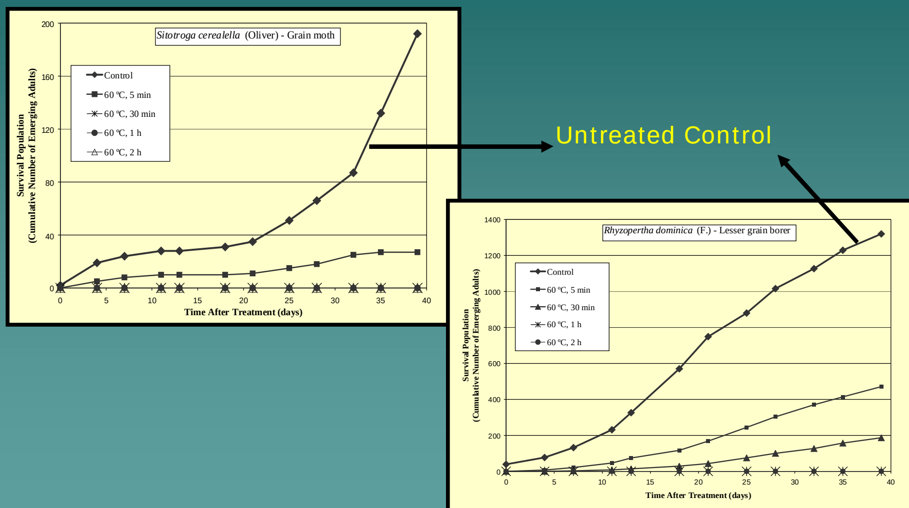
**Table 1. Efficacy of RF power (~ 14.9 MHz, 500 W) disinfection for various temperatures for *Salmonella typhimurium* inoculated almond samples. Samples incubated for 72 h at 37°C.**

| RF processing | Almond samples (n = 6) | Initial (av.) inoculums (cfu/mL) | Colonies detected. | $Log_{10}$ reduction |
|---|---|---|---|---|
| | Batch 1 | | | |
| None | Control | $2.2 \times 10^7$ | All positive | None |
| 90°C (+ 5 min) | RF Treated | $2.2 \times 10^6$ | All negative | ~ 6 |
| | RF Treated | $2.2 \times 10^7$ | All negative | ~ 7 |
| | Batch 2 | | | |
| None | Control | $2.2 \times 10^7$ | All positive | None |
| 80°C (+ 5 min) | RF Treated | $2.2 \times 10^6$ | All negative | ~ 6 |
| | RF Treated | $2.2 \times 10^7$ | All negative | ~ 7 |
| | Batch 3 | | | |
| None | Control | $2.2 \times 10^7$ | All positive | None |
| 70°C (+ 5 min) | RF Treated | $2.2 \times 10^6$ | All negative | ~ 6 |
| | RF Treated | $2.2 \times 10^7$ | All negative | ~ 7 |



# RF Disinfestation of Paddy Rice – Experimental Procedures

## RF disinfestation of grain moths (*Sitotroga cereallela)* and grain borers (*Rhyzopertha dominica)* in rough (paddy) rice. Controls (not treated) and RF treated samples in triplicate.






# RF Disinfestation of Paddy Rice

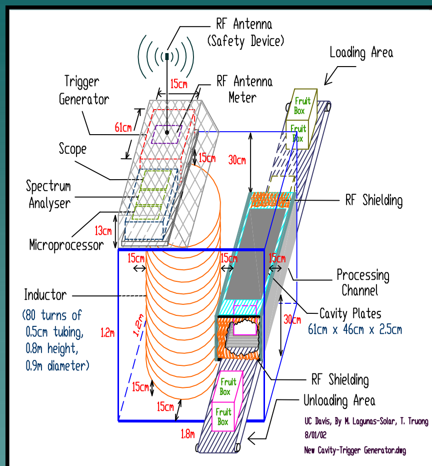
- Results of milling quality tests: No statistical change between control and RF treated at 50º, 60º, and 70ºC.

**Quality attributes of RF-processed paddy rice***
**(Analyzed by California Rice Industry, Sacramento, CA)**

| | | RF treatment | | |
|---|---|---|---|---|
| Quality attributes | Controls | 50ºC | 60ºC | 70ºC |
| | ……………………………%…………………………………… | | | |
| Moisture | 13.5 ± 0.1 | 13.5 ± 0.1 | 13.5 ± 0.1 | 13.5 ± 0.1 |
| Whole kernel | 79.3 ± 1.1 | 81.1 ± 7.9 | 78.3 ± 0.5 | 77.9 ± 0.8 |
| Total rice | 68.1 ± 0.3 | 68.3 ± 0.1 | 68.2 ± 0.1 | 68.0 ± 0.1 |
| Dockage | 16.9 ± 4.8 | 11.7 ± 1.0 | 12.4 ± 1.6 | 13.2 ± 1.7 |
| Brown rice | 81.1 ± 0.4 | 81.4 ± 0.2 | 81.3 ± 0.2 | 81.3 ±0.1 |
| Whiteness | 44.2 ±0.2 | 44.1 ± 0.2 | 44.2 ± 0.2 | 44.3 ± 0.3 |

(*) Mean values and standard deviation for triplicate measurements, each with 1-kg samples.

# RF Prototype Development at UC Davis

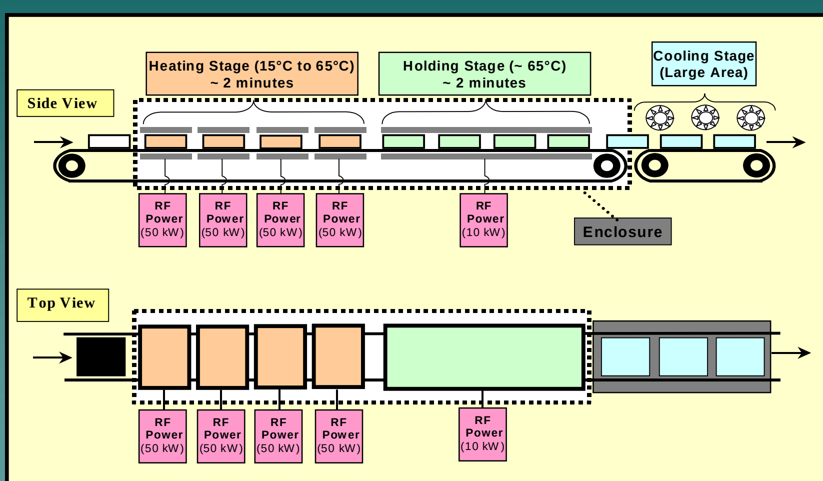



Under development
(Since 2004)

New RF Module (2009)



# Modular RF Processing Approach:
# (250 kW (total) - ~ 4 tons/h capacity)




Modular D&E allows for energy-use optimization in large- scale operations.

## Economics of RF Processing (*)

• **Fluids**

**Wastewater:** $0.004/liter (~ 315 lpm) (1,000 animals)
RF Power: 1.6 MW

**Liquid Milk:** $0.004/liter (~380 lpm)
RF Power: 1.6 MW

**Fruit Juices:** $0.004/liter (~ 380 lpm)
RF Power: 1.6 MW

• **Solids**

**Fishmeal:** < $15.00/ton (4 ton/h)
RF Power: 0.25 MW

**Grains/Seeds:** $0.0156 bushel ($0.00044/liter) (400 bushel/h)
RF Power: 0.10 MW (1 bushel = 35.44 L)

**Herbs:** $0.0062/Kg (950 kg/h)
RF Power: 55 kW

**Almonds:** $0.0032/kg (2.6 ton/h)
RF Power: 0.10 MW

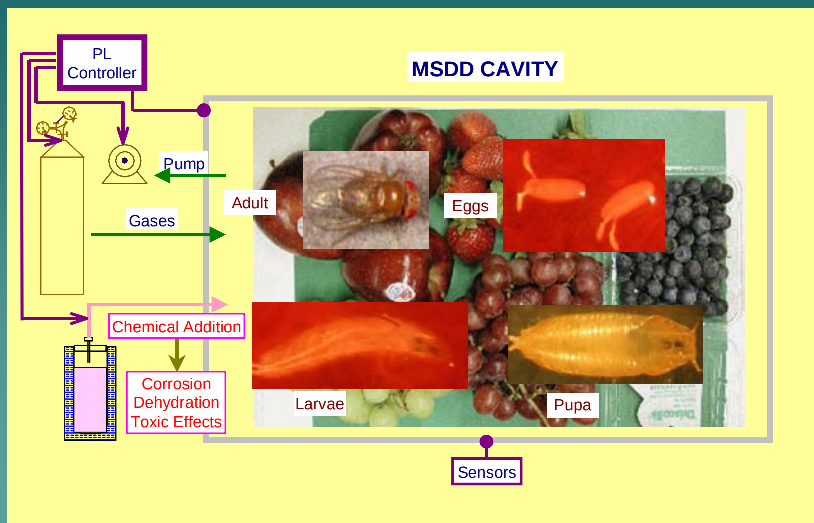
**(*) Cost estimates based solely on electric power consumption.**



## MSDD Mechanisms for Insect/Mite Controls

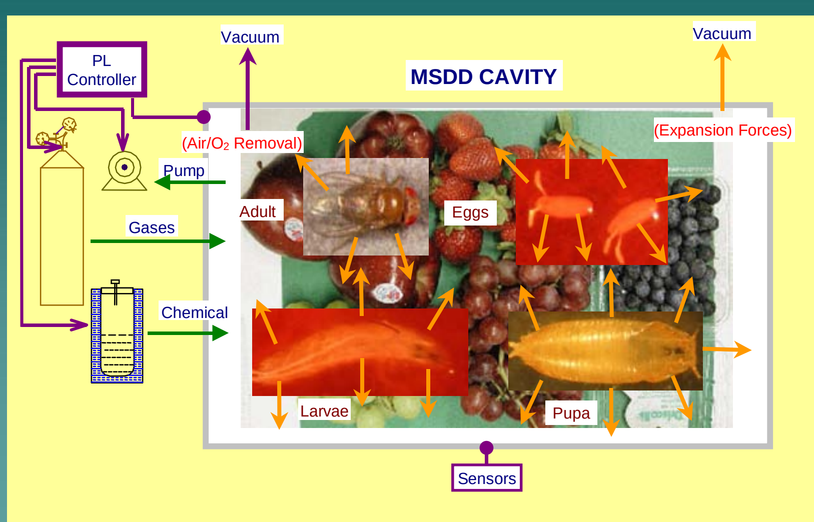
- Anatomical Stress: Uses rapid pressure oscillation cycles to apply expansion and compression mechanical forces. Forces induce changes in Biological Structures and Cell Permeability.
- Respiratory Stress: the expansion/compression forces open air sacs in insect/mites, formed as a response to any stress, and eliminate air reserves used to survive long periods. Stress causes Anoxia and modifications of Gaseous Equilibrium.
- Functional Stress: At cellular level, the pressure cycles displaces the Oxygen gas/liquid equilibrium and modify cellular pH.
- Chemical Stress: use of volatile chemicals increases toxicity, add dehydration effects, corrosion of membranes and tissues, and facilitates disinfection.

# MSDD Process System – Components & Functions

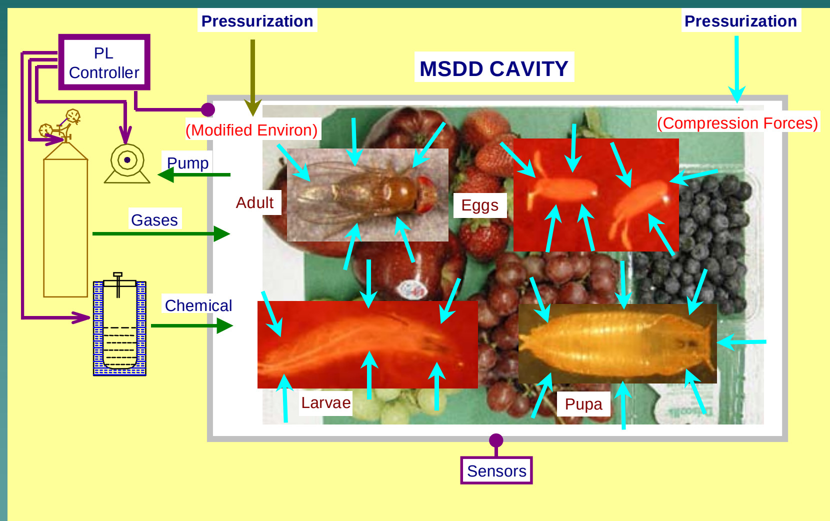





# MSDD Process System – I. Expansion Cycle

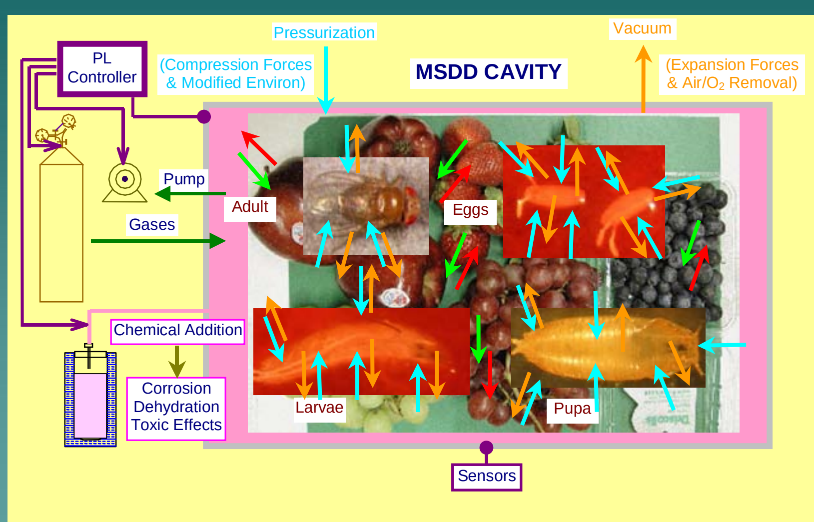


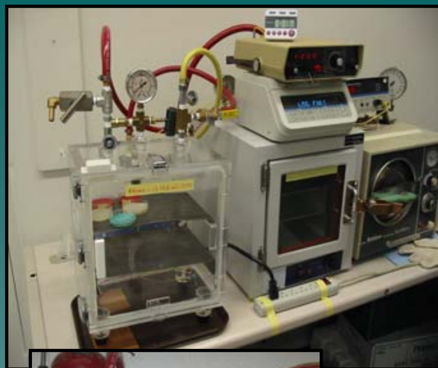
# MSDD Process System – Compression Cycle



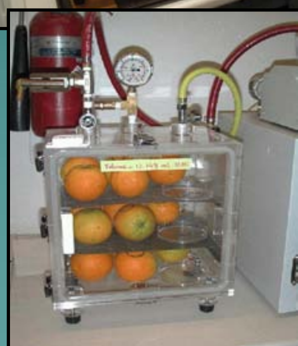



# MSDD Process System – Chemical Cycles





# MSDD Research Systems Crocker Nuclear Laboratory UC Davis





## Summary of Results for MSDD Disinfection

| Organisms | Initial (CFU/mL) | Final (CFU/mL) |
|---|---|---|
| *Botrytis cinerea* | $3.0 \times 10^4$ | No colonies detected |
| *Penicillium spp.*<br>*P. digitatum (dry spores)* | $9.0 \times 10^4$<br>$4.0 \times 10^6$ | No colonies detected |
| *Alternaria alternata* | $1.2 \times 10^4$ | No colonies detected |
| *Rhizopus spp.* | $1.8 \times 10^4$ | No colonies detected |
| *Salmonella spp.* | $1.0 \times 10^5$ | No colonies detected |
| *Escherichia coli spp.* | $1.0 \times 10^5$ | No colonies detected |
| *Staphylococcus aureus* | $1.0 \times 10^5$ | No colonies detected |

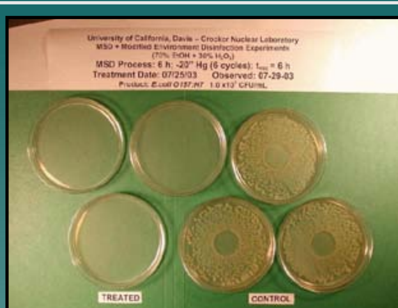
## Metabolic Stress Disinfestation and Disinfection (MSDD)

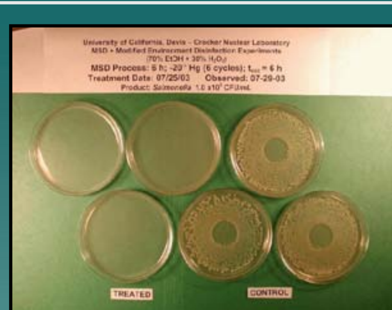
## Summary of MS Fungal Disinfection Results

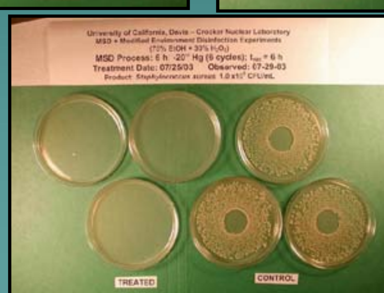



UC Davis Results (August 2003)

## Summary of MSDD Human Pathogen Disinfection

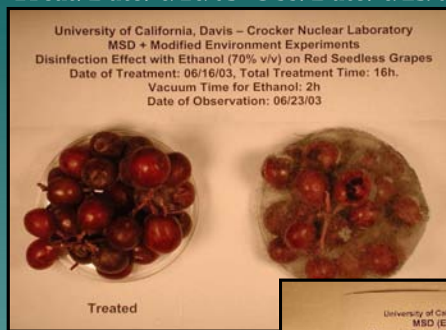


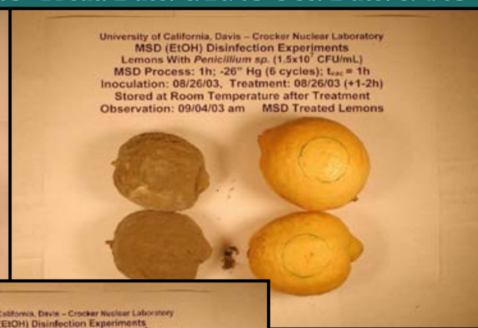



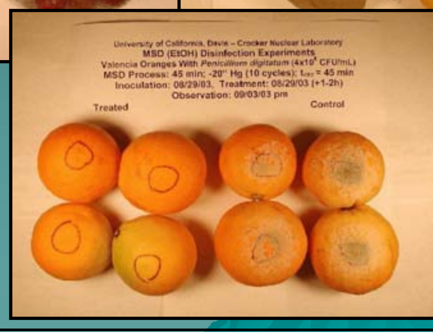



## Results of MSDD Fungal Disinfection.

Treat. Date: 6/16/03 Obs. Date: 6/23/03 Treat. Date: 8/26/03 Obs. Date: 9/4/03




Treat. Date: 8/26/03

Obs. Date: 9/3/03

## Results of MSDD Sub-epidermal Fungal Disinfection. (*)

Valencia Oranges Inoculated with *P. digitatum* (Dry Spores)
Treatment Date: Aug. 28, 2003 Observation Date: Sept. 4, 2003
DTime = ~ 7 days. Storage at ~ 22°C

Controls

MSDD Treated

(*) Collaboration with Sunkist Growers Inc.

## Results of MSDD Fungal Disinfection (Asparagus).

**Commercial Asparagus (Perú) – Control and MSDD Treated Samples**
**Treat. date: Sept. 24, 2003   Obs. date: Sept. 24, 2003**


Control Samples

MSDD Treated Samples



## Results of MSDD Fungal Disinfection (Asparagus).

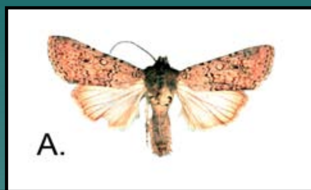
**Controls**

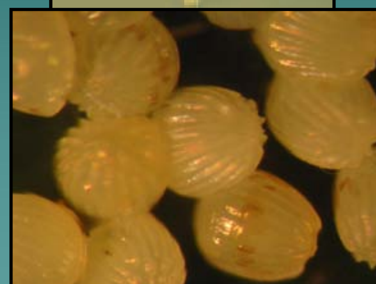
**(DTime = 10 days at 22ºC)**

**MSDD Treated**

**(DTime = 10 days at 22ºC)**

## *Copitarsia decolora & Heliothis virescens*





## *Ceratititis capitata*

## *Anastrepha spp*

## *Drosophila melanogaster*

## Summary of MSDD Disinfestation Results

| Insect/Mite | Life Stage | Time (h) | Mortality (%) |
|---|---|---|---|
| *Drosophila melanogaster* (Fruit Flies) | Adults | 9<br>10<br>12 | 96 (77/80)<br>>99 (88/89)<br>100% (55/55) |
| *Frankliniella occidentalis* (Thrips) | Adults<br>Pupas<br>Eggs | 7<br>8<br>8 | 100 (120/120)<br>>93 (186/200)<br>>93 (156/167) |
| *Myzus Persicae* (Aphids) | Adults | 7 | 100 (20/20) |
| *Tetranychus urticae* (Mites) | Adults<br>Juveniles<br>Eggs | 6<br>6<br>6 | >99 (198/200)<br>>90 (205/225)<br>>80 (525/655) |
| *Amblyseius cucumeris* (Mites) | Adults | 7-10 | >98 (294/300) |



## Summary of MSDD Disinfestation Results*

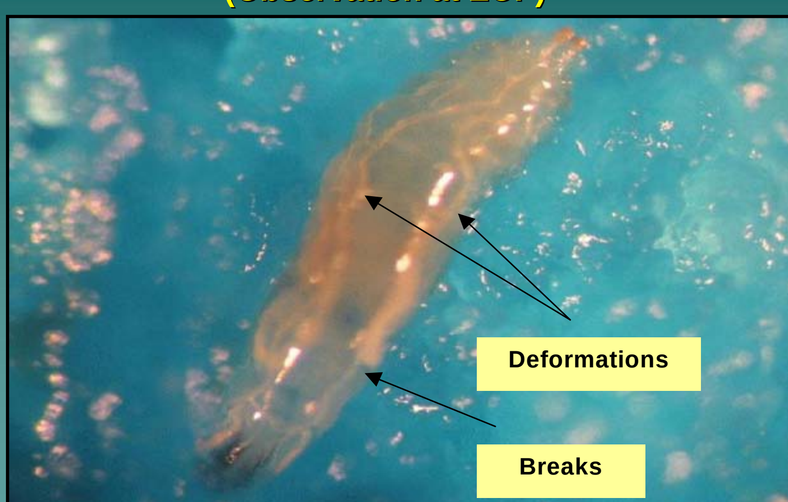
| Insects | Life Stage | Time (h) | Mortality (%) |
|---|---|---|---|
| ***Heliothis virescens*** *(Surrogate for Copitarsia spp.)* | Adult<br>Pupae<br>Larvae<br>Egg | < 0.4<br><0.4<br><0.4<br>0.7 – 1.5 | 100<br>100<br>100<br>100 |
| ***Drosophila melanogaster*** *(Surrogate for Fruit Fly spp.)* | Adult<br>Pupae<br>Larvae<br>Egg | < 0.4<br><0.4<br><0.4<br>1 – 2 | 100<br>100<br>100<br>100 |

**(*) Results of cumulative experiments conducted with ~ 5,000 control and ~ 5,000 treated samples for each life stage and insect species.**

## MSDD Effects on *Heliothis virescens* (Eggs)


UC Davis (May 2009)

## MSDD Effects on Tracheal System of *Drosophila melanogaster* (Larvae). (Observation at EOP)

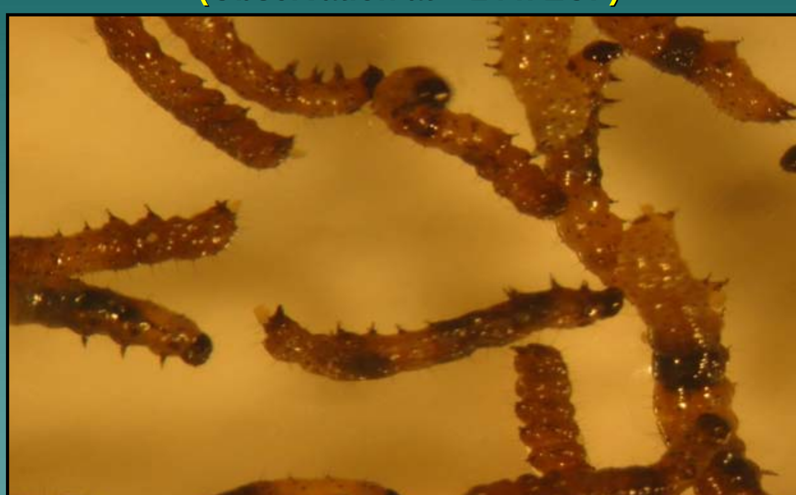


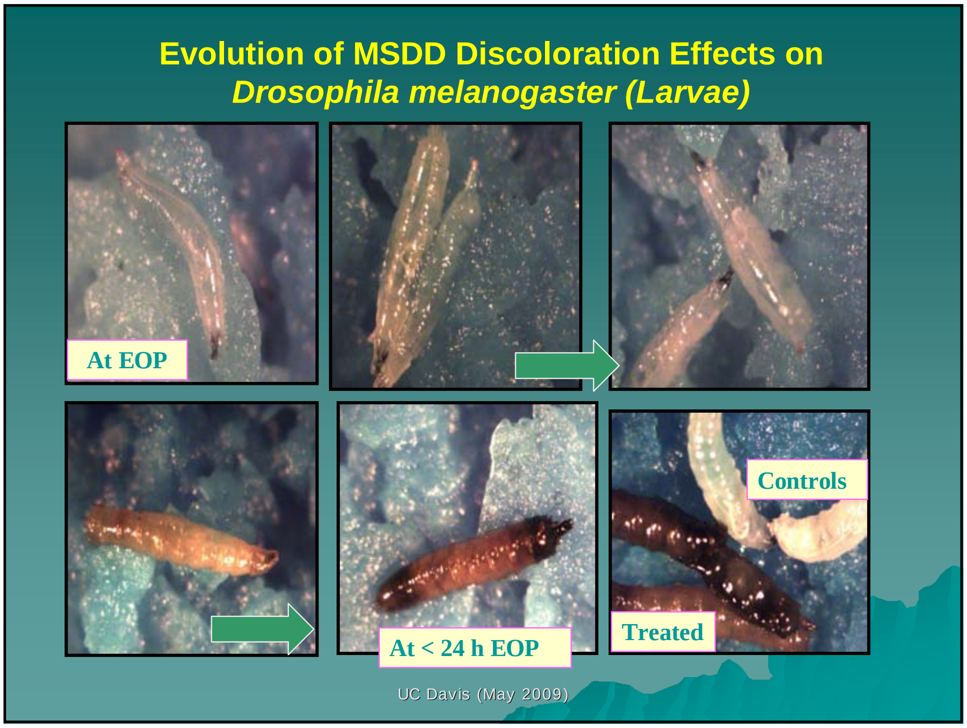

UC Davis (May 2009)

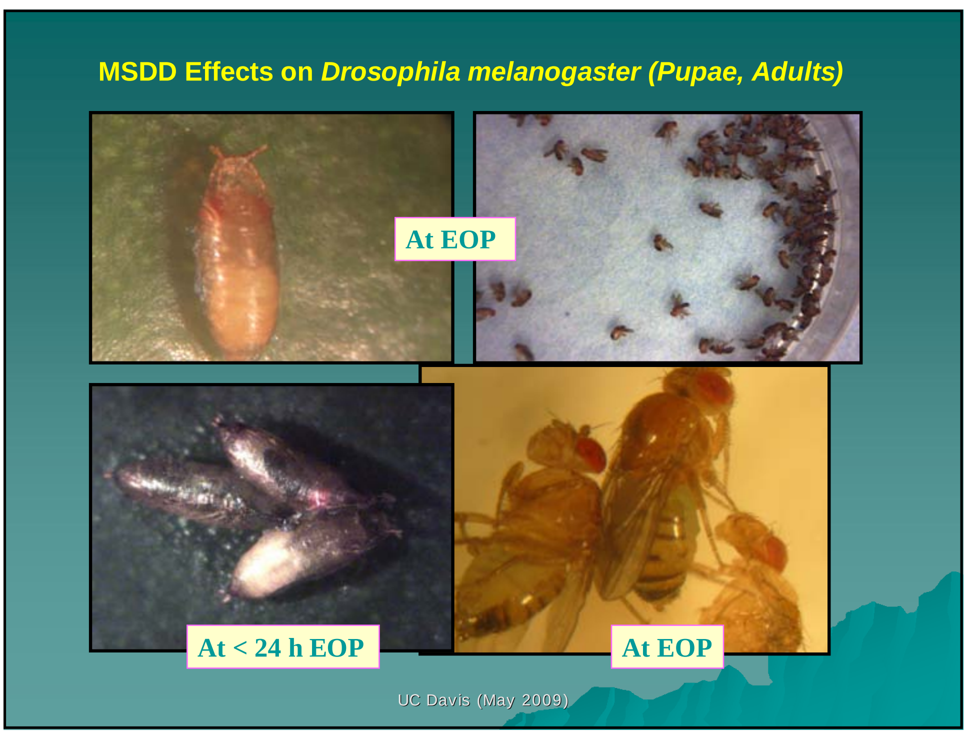
## MSDD Effects on Tracheal System of *Drosophila melanogaster* (Larvae)




## MSDD Effects on *Drosophila melanogaster* (Larvae). Combined Effects (Discolorations, Deformations, etc.) (Observation at < 24 h EOP)

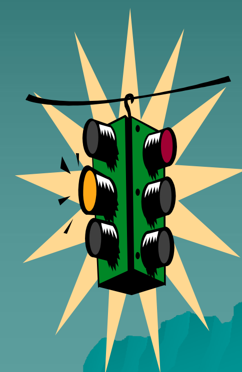



Evolution of MSDD Discoloration Effects on
*Drosophila melanogaster (Larvae)*
At EOP
Controls
Treated
At < 24 h EOP
UC Davis (May 2009)


MSDD Effects on *Drosophila melanogaster (Pupae, Adults)*
At EOP
At < 24 h EOP
At EOP
UC Davis (May 2009)

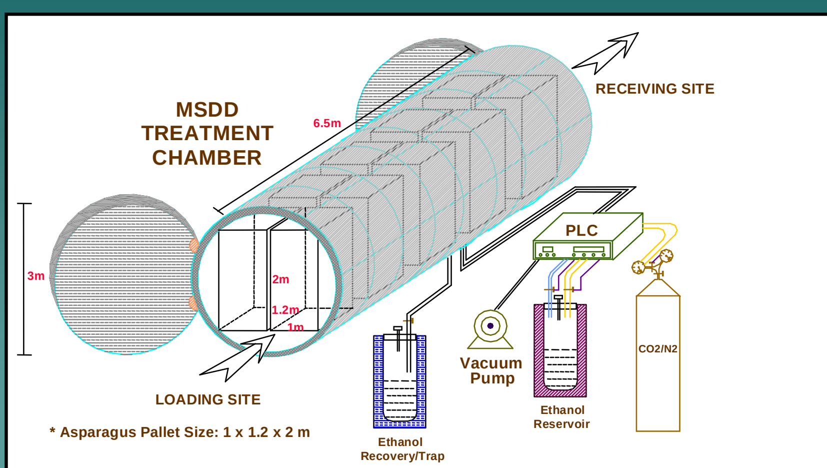
## Summary of Potential MSDD Uses

- Bush Berries
  (blueberries, raspberries, blackberries, strawberries)
- Table Grapes
  (Thompson, Flame, and Red seedless)
- Citrus Fruits
  - Oranges (Navel, Valencia)
  - Lemons (Eureka)
- Bananas
- Asparagus (Spain, Perú, USA)
- Lettuces (Iceberg)
- Stone Fruits
- Grains (rice)

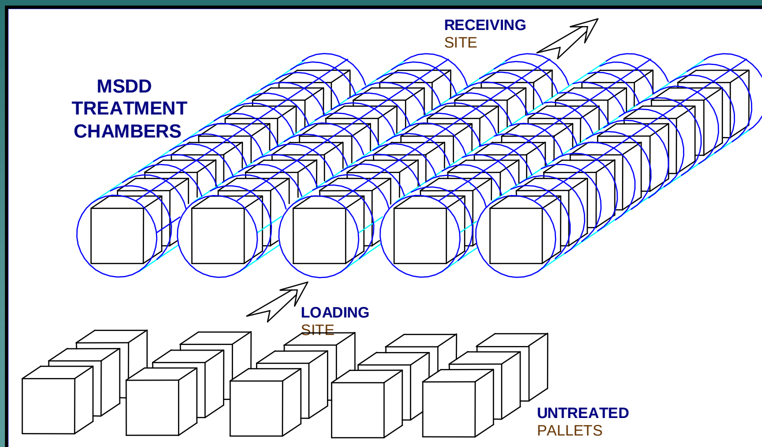




## MSDD Pre-Commercial Prototype System

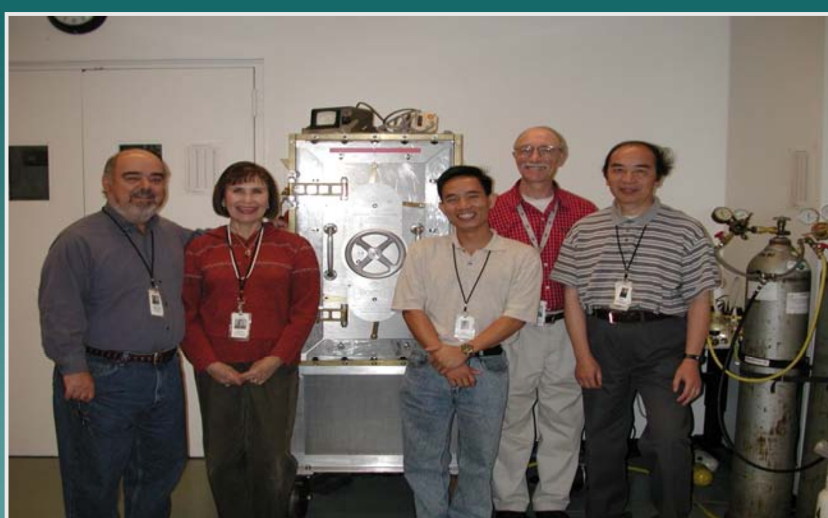


## MSDD Pre-Commercial Prototype System. Installation & Operation Concept






## UC Davis RF & MSDD Project (1998-2009)



M. Lagunas-Solar, Cecilia Piña, Tin Truong, Tim Essert, Nolan Zeng