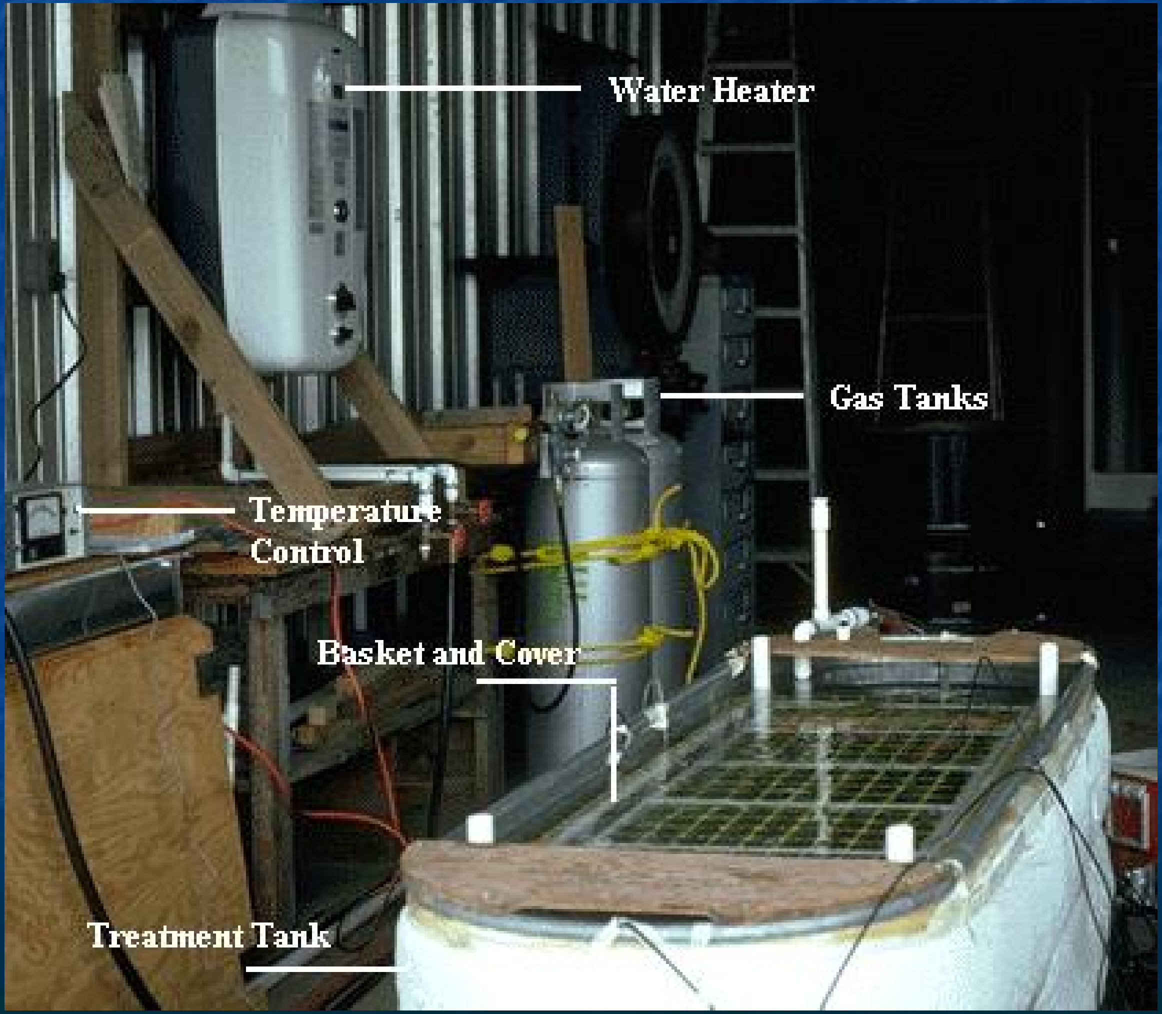
Effects of heat and modified atmospheres on insects

Lisa G. Neven
USDA-ARS
Yakima Agricultural Research Laboratory
Wapato, WA

Heat Treatments For Fresh Commodities

- Types of Treatments
  - Hot Water (Dips, drenches, or sprays)
  - Vapor Heat
  - Hot Forced Air (non-condensing)
  - Microwaves
  - Radio Frequency
- Types of Responses
  - Metabolism
  - Respiration
  - Nervous System
  - Endocrine
  - Heat Shock Proteins

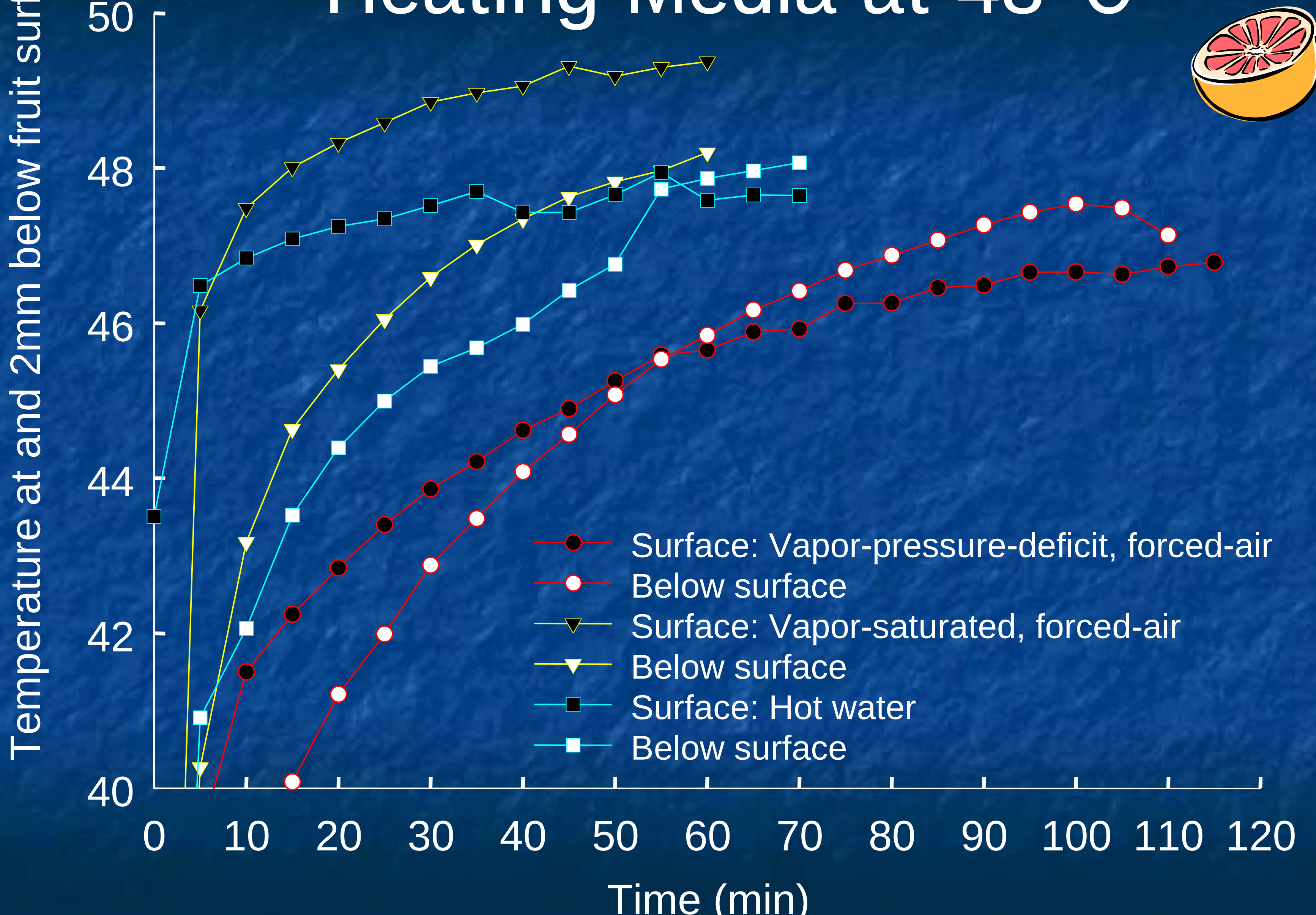
Hot Water Dips



Hot Forced Air

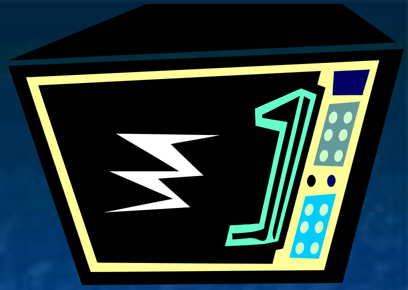
Factory Hot Forced Air

Heating Media at 48°C



K. Shellie, USDA-ARS

Electromagnetic Energy



- Is it heat?
- Is it radiation?
- Is it something else? (dielectric effect)

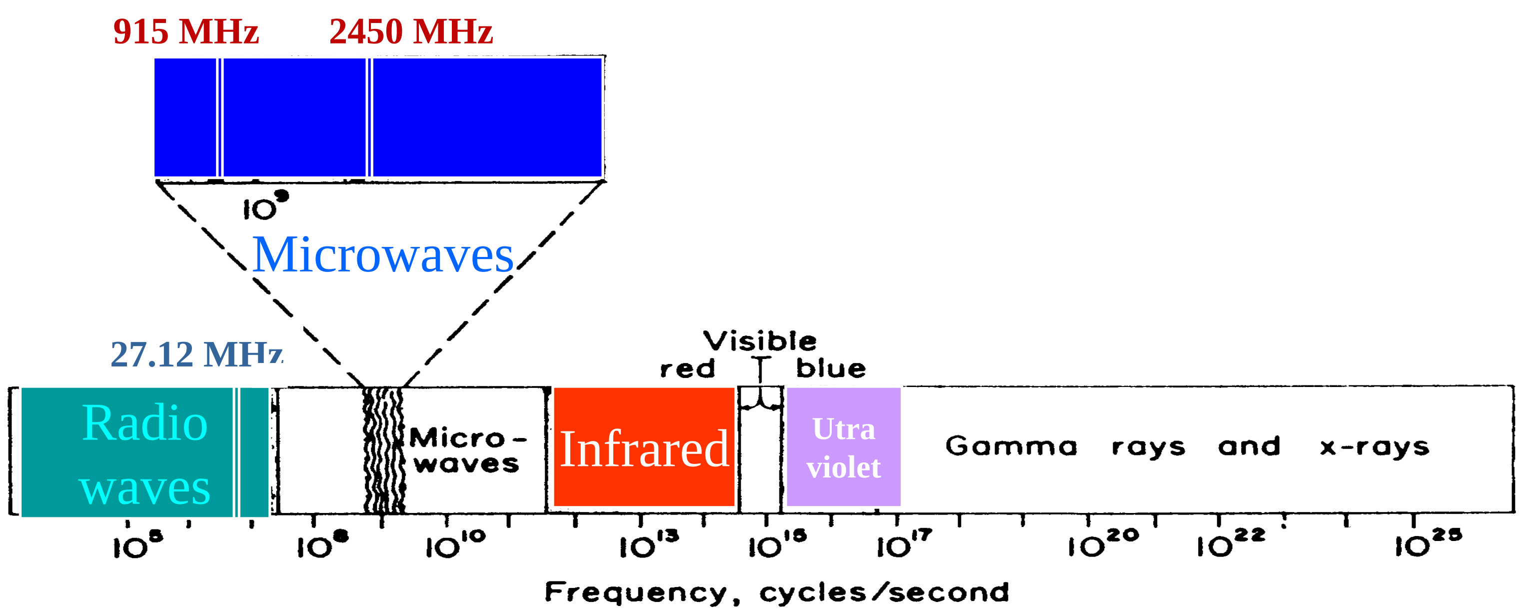
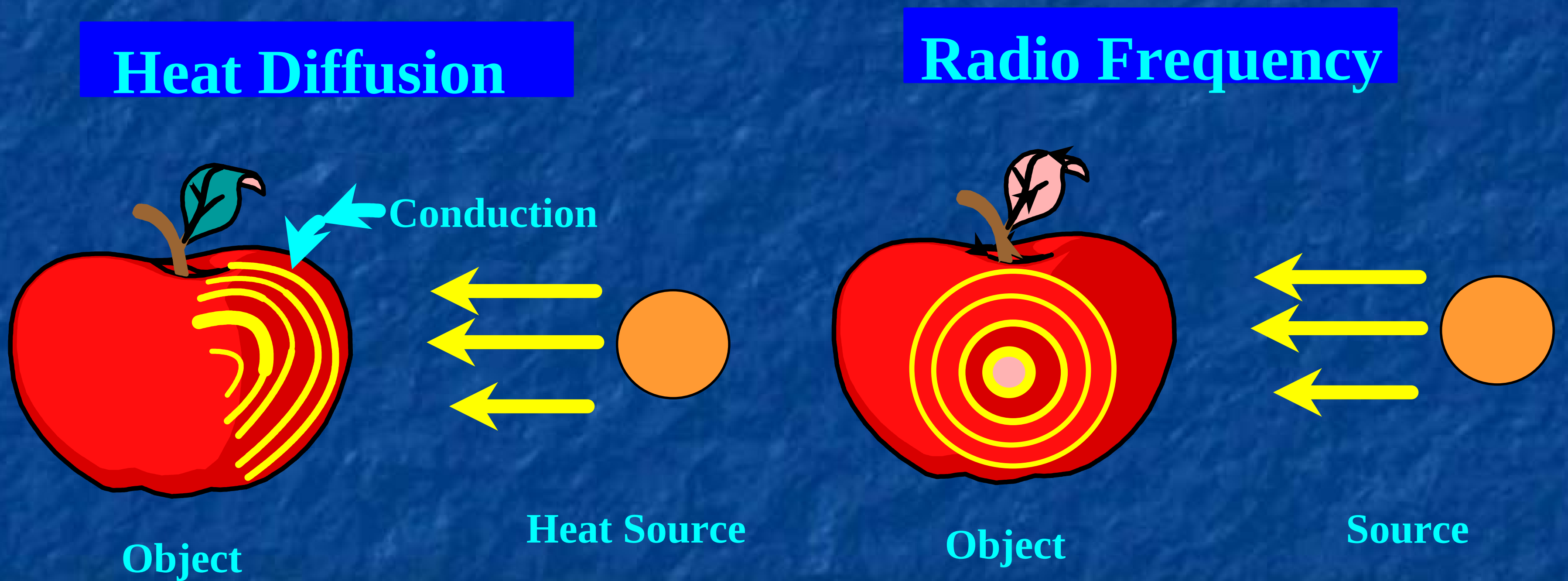


Fig. 1. Electromagnetic spectrum (courtesy Cryodry Corp.).

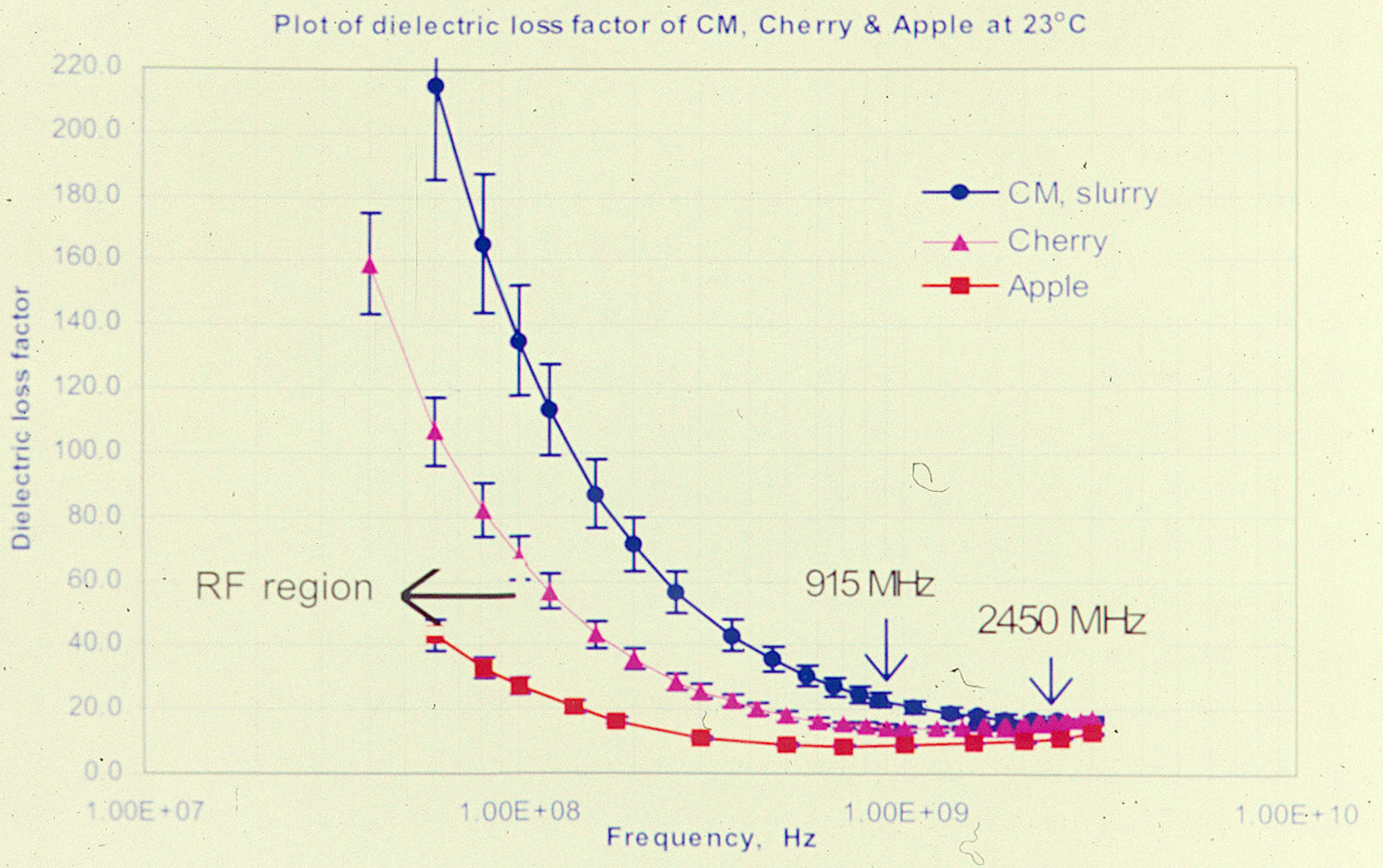
Comparison of Thermal and Radio Frequency Treatments



James Hansen, USDA-ARS, USA

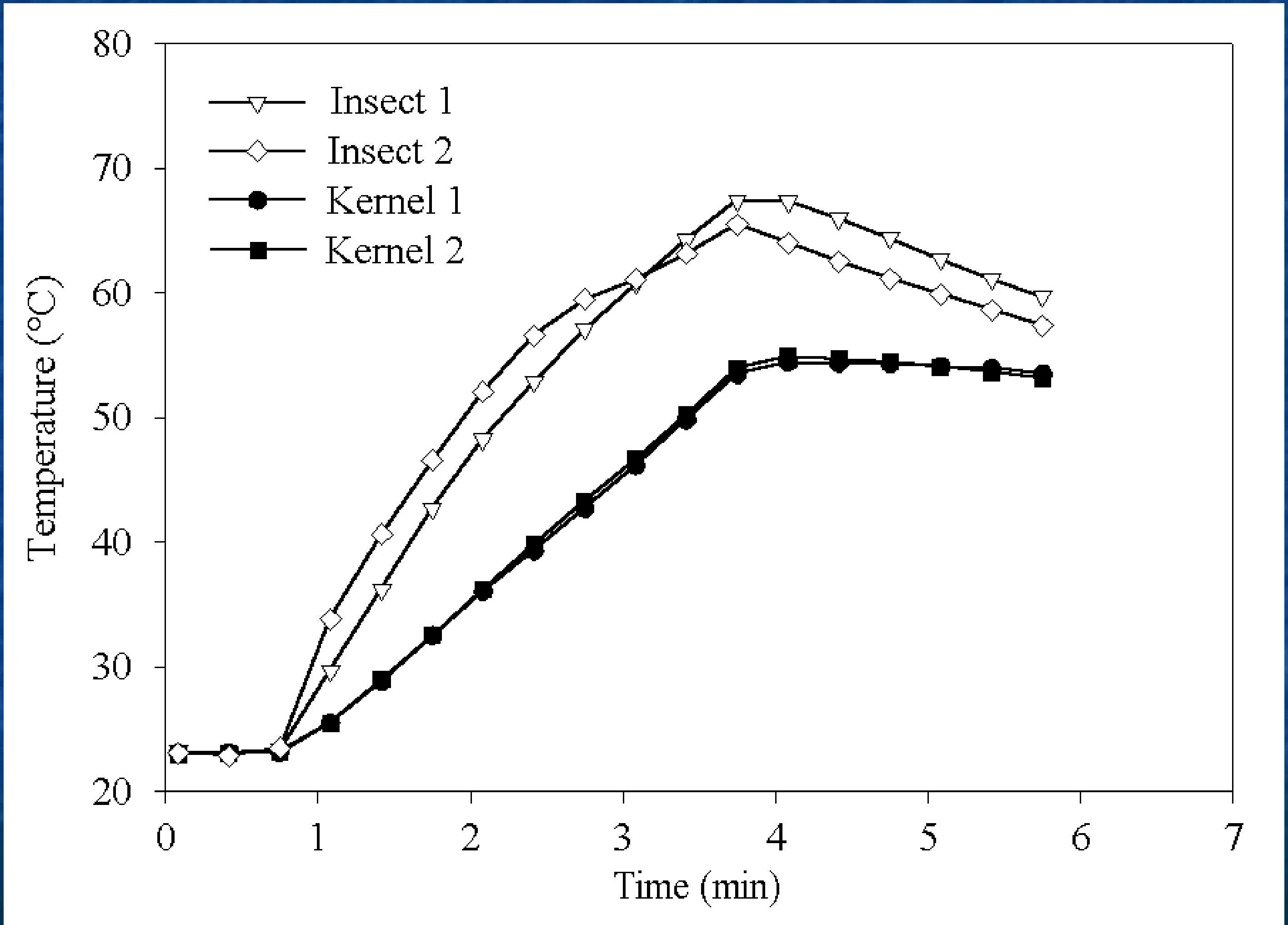
Radio Frequency Treatments

- See a higher level of mortality over that which can be explained by thermal mortality.
- It appears to be part thermal and part dielectric effects on mortality.



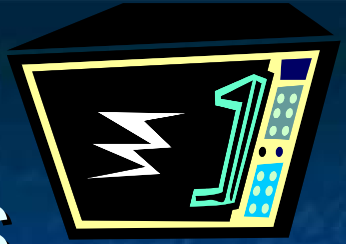
James Hansen, USDA-ARS, USA

Temperature profiles of walnut kernels and codling moth slurry when subjected to 27 MHz RF system



(S. Wang and J. Tang, WSU)

Microwave Treatments



- Appears to be very effective in treatment of insects in dry commodities.
- Insects heat faster due to water content.
- Some limited success in fresh produce.
- Mortality still an effect of heating.

Terminology of Temperature Change

- **Step Function**: refers to a change from one temperature to another as rapidly as possible
  - Step-function transfers reveal how rapidly an insect can respond to a thermal challenge.
  - Example: water bath studies in which insects are immersed directly into heated water (or other aqueous medium) (Sharp and Chew 1987, Jang 1991)

(Clarke 1967)

Terminology of Temperature Change

- **Ramp Function**: is when a slower rate of change in temperature occurs
  - Ramp-function heat treatments can reveal, through examination of the response curve, what mechanisms may be involved in thermal tolerance and indicate whether the tolerance limits of the insect is wider in response to a ramp than to a step function.
  - Example: In-fruit heat treatments or controlled water bath treatments (Shellie 1997, Neven 1998a,b)

(Clarke 1967)

Important Factors Affecting Heat Treatments

- Temperature of treatment
  - Insect thermal limits
- Rate of heating
  - Acclimation vs. acclimatization
- Duration of heat treatment
  - Range from sub-lethal to lethal responses
- Insect Milieu
  - Location in commodity
  - Physical state of commodity surrounding insect

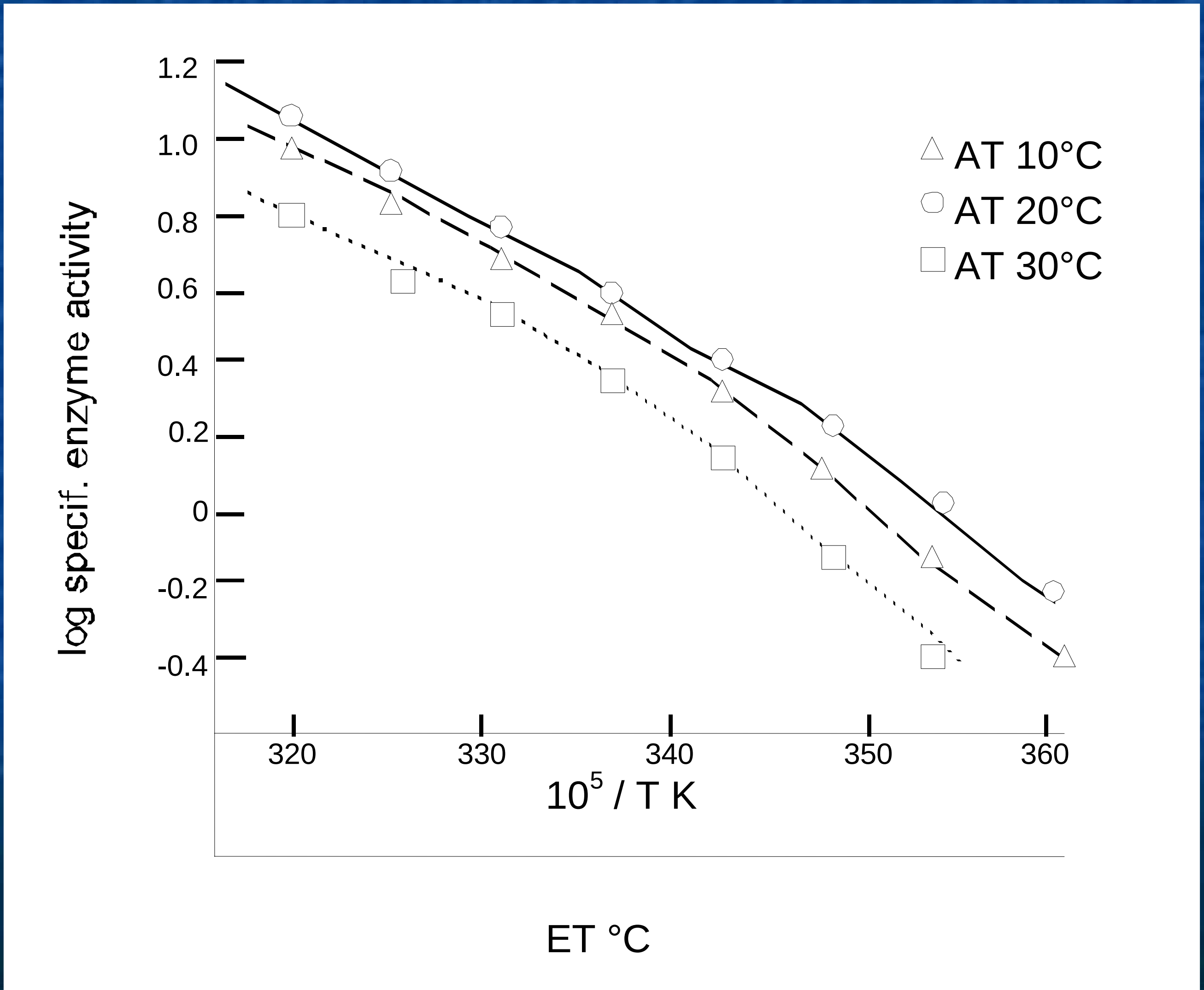
Q_{10} Effects

$$Q_{10} = \frac{\text{Velocity } (T° + 10°)}{\text{Velocity } (T°)}$$

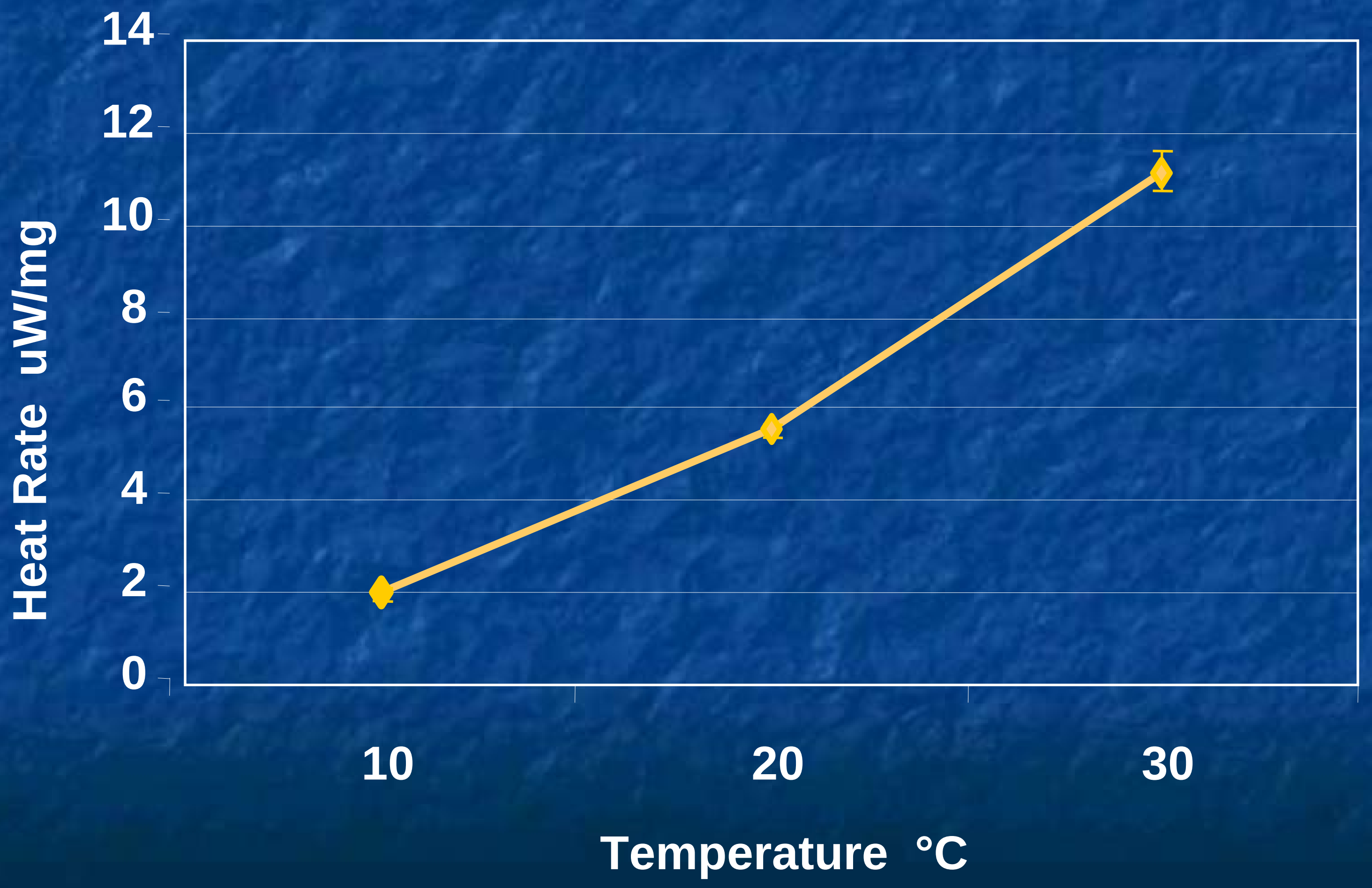
OR

$$Q_{10} = \left(\frac{k_2}{k_1}\right)^{10/\,(T°_2 - T°_1)}$$

Arrhenius plots of PK activity from muscle and fat body of *Acheta domesticus* after periods at various acclimation temperatures. (After Hoffman and Marstatt 1977).

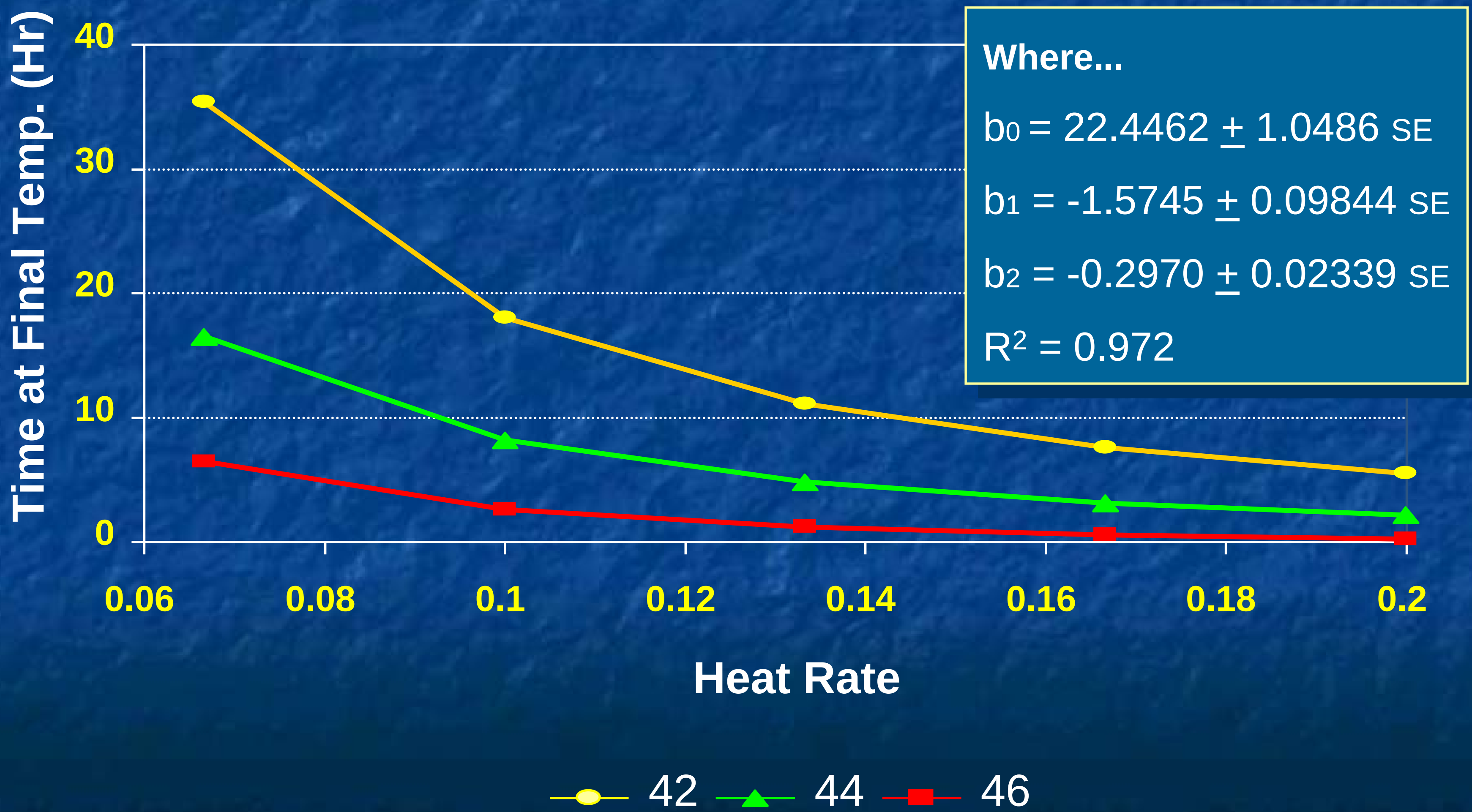


Temperature Effects on Metabolism



Time at Final Temperature versus Heating Rate

$\ln(LT_{95}) = b_0 + b_1 \ln(\text{heat rate}) + b_2\,(\text{treatment temperature})$



Where...

$b_0 = 22.4462 \pm 1.0486$ SE

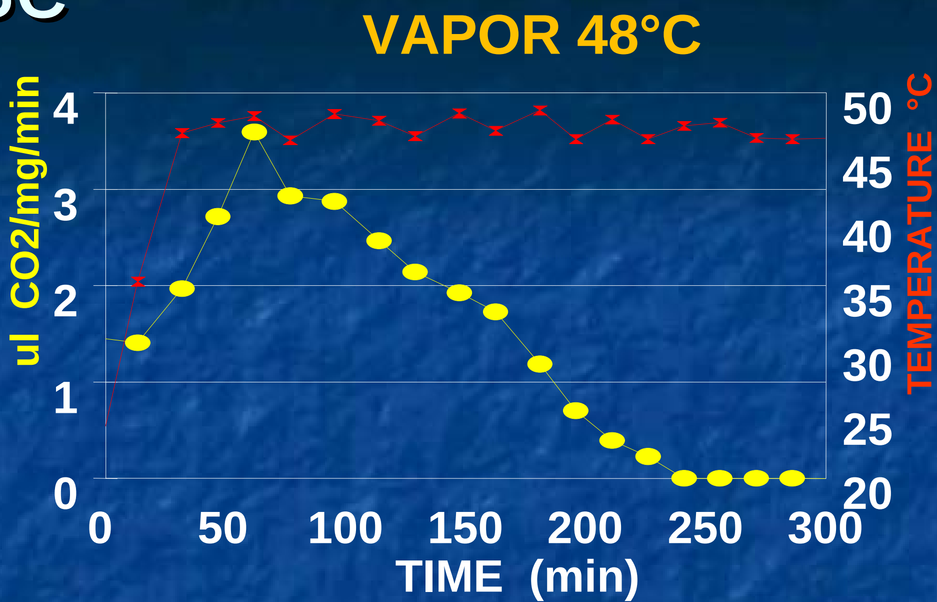
$b_1 = -1.5745 \pm 0.09844$ SE

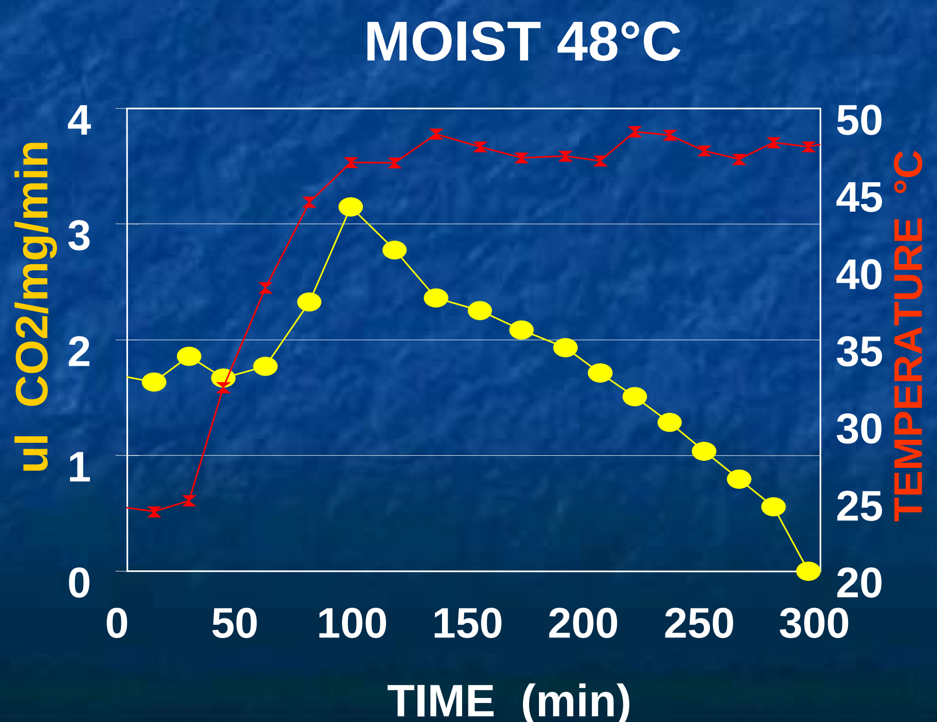
$b_2 = -0.2970 \pm 0.02339$ SE

$R^2 = 0.972$

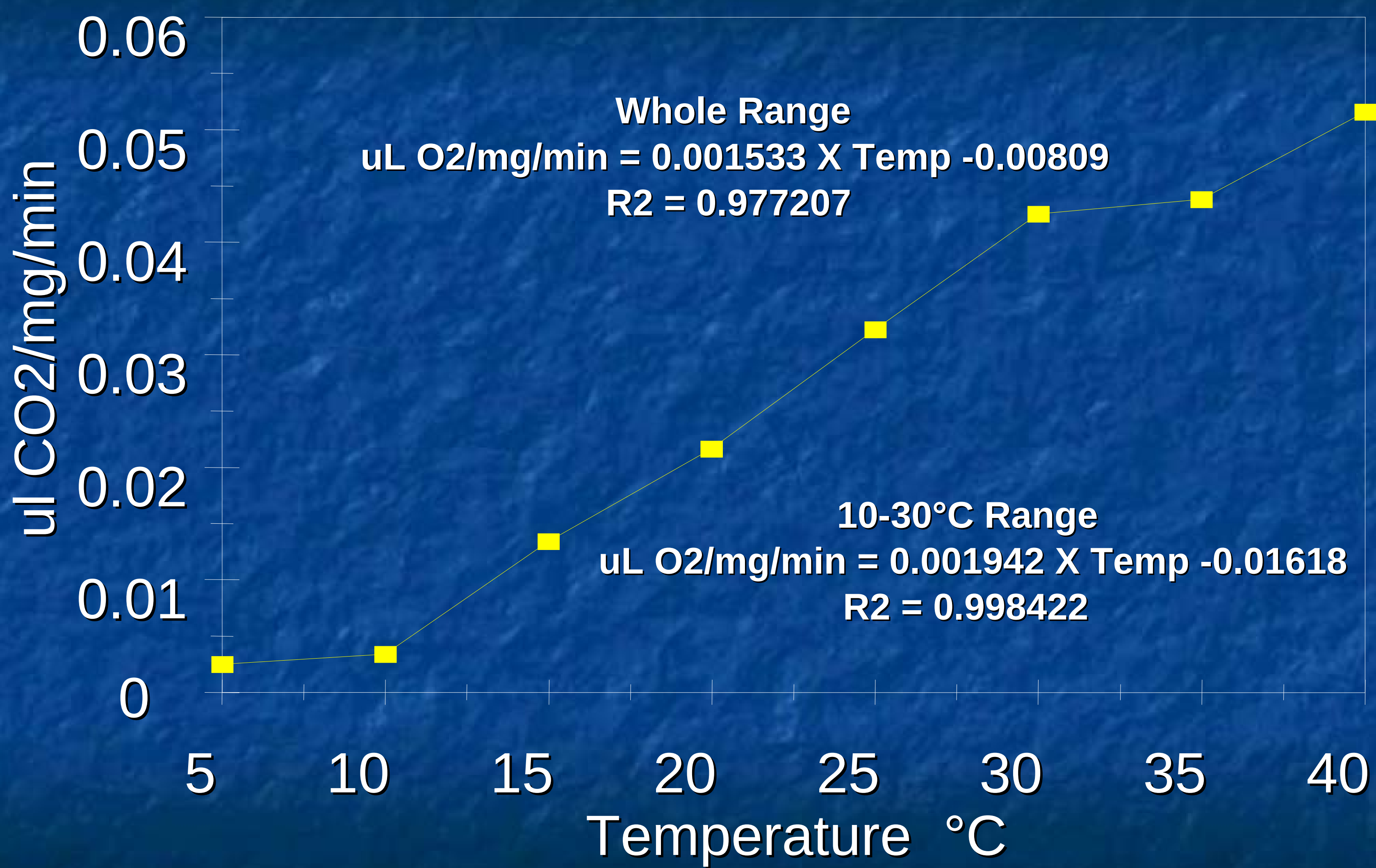
Respiratory Response to Heat Treatment

- Fifth instar codling moth CO_2 production during a simulated heat treatment of apple
- Note characteristic peak followed by rapid decline in CO_2 production.

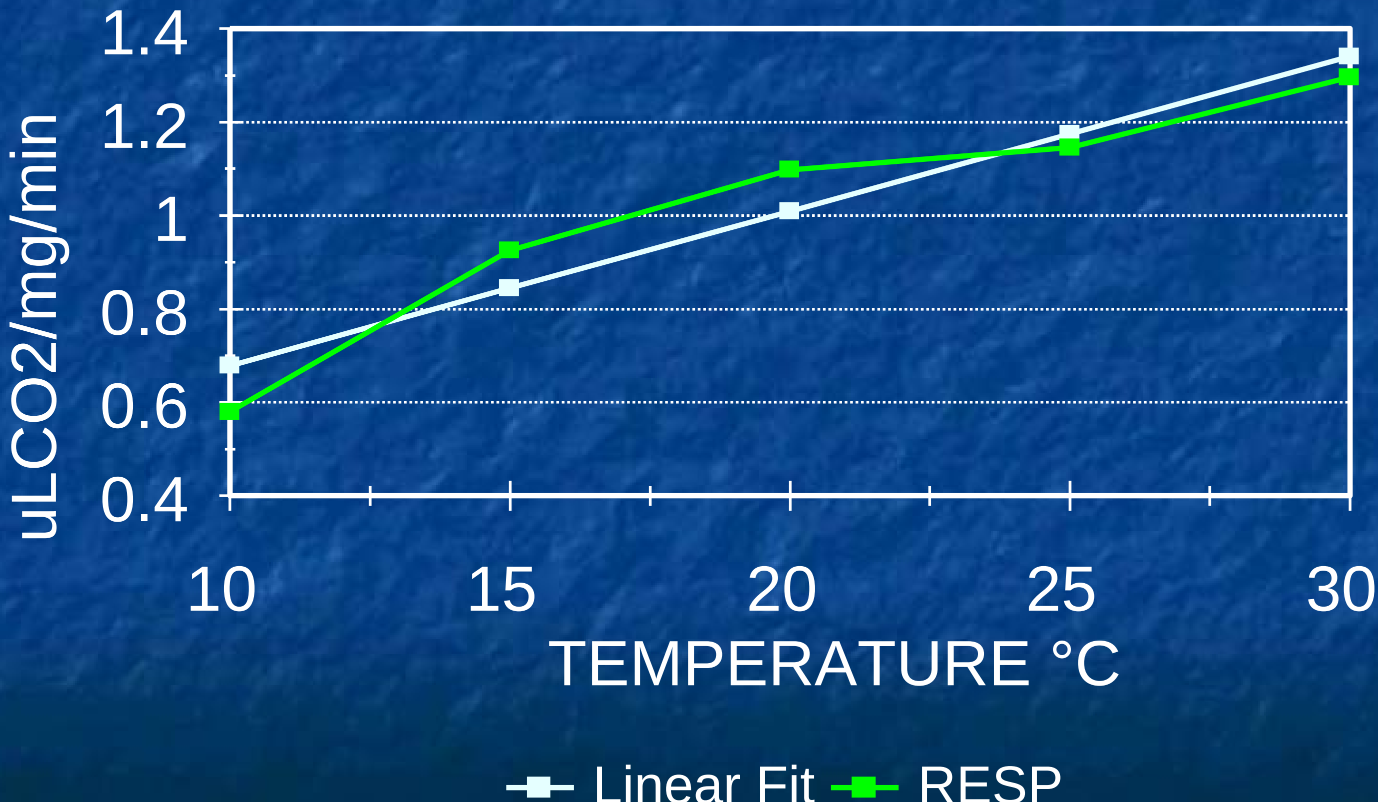




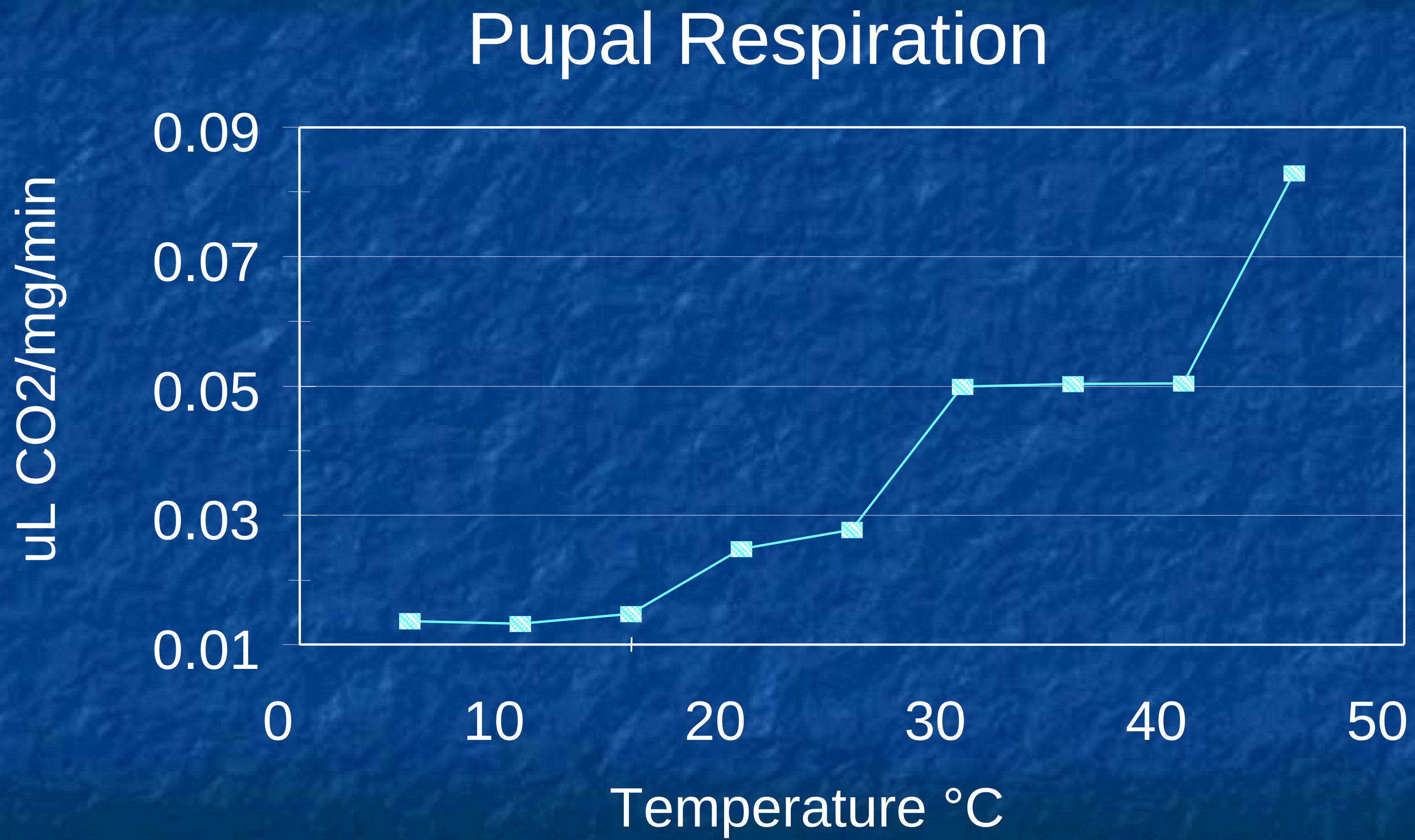
Codling Moth Pupal Respiration

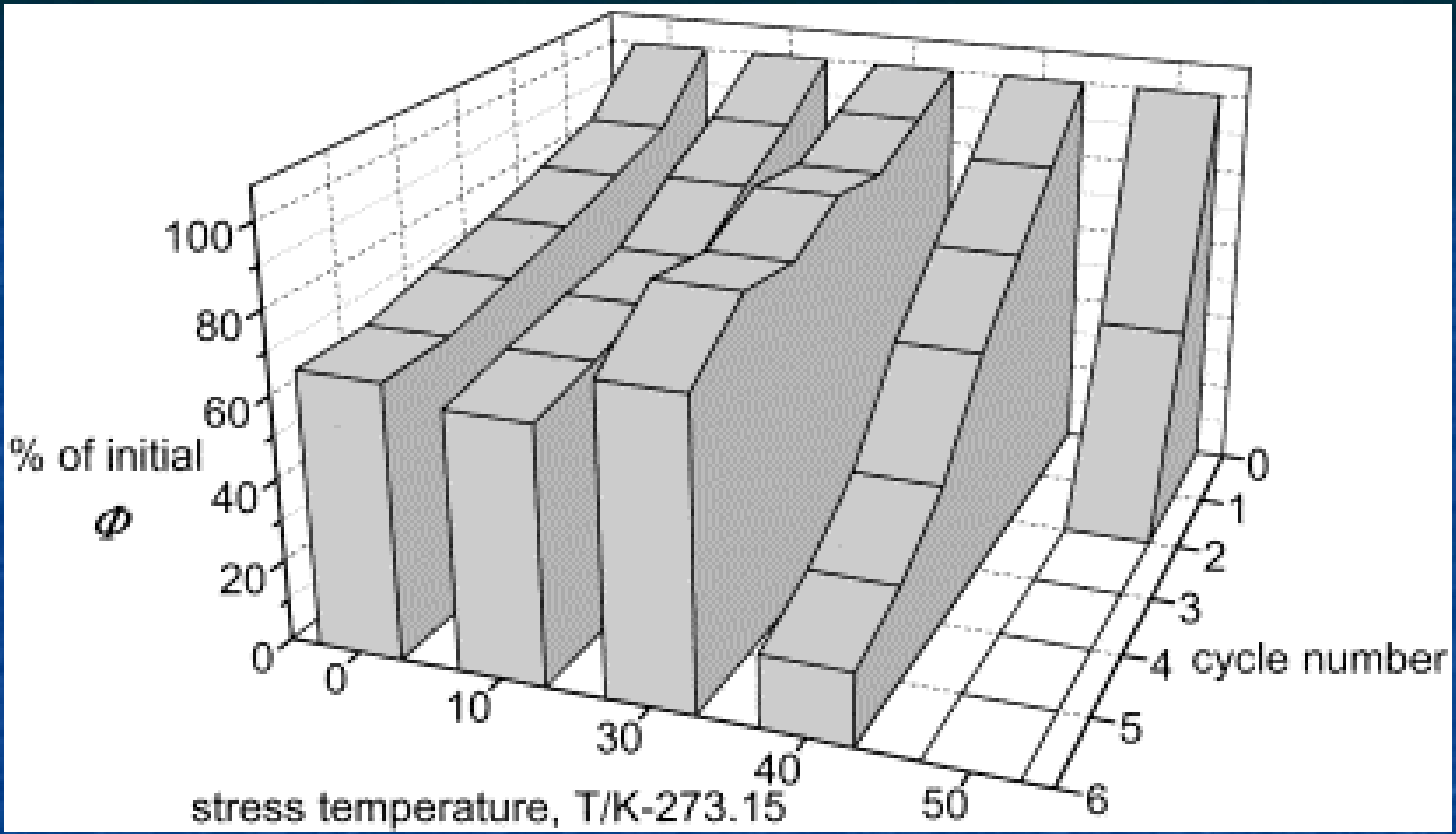


Respiration of fifth instar codling moth at constant temperature



Omnivorous Leafroller

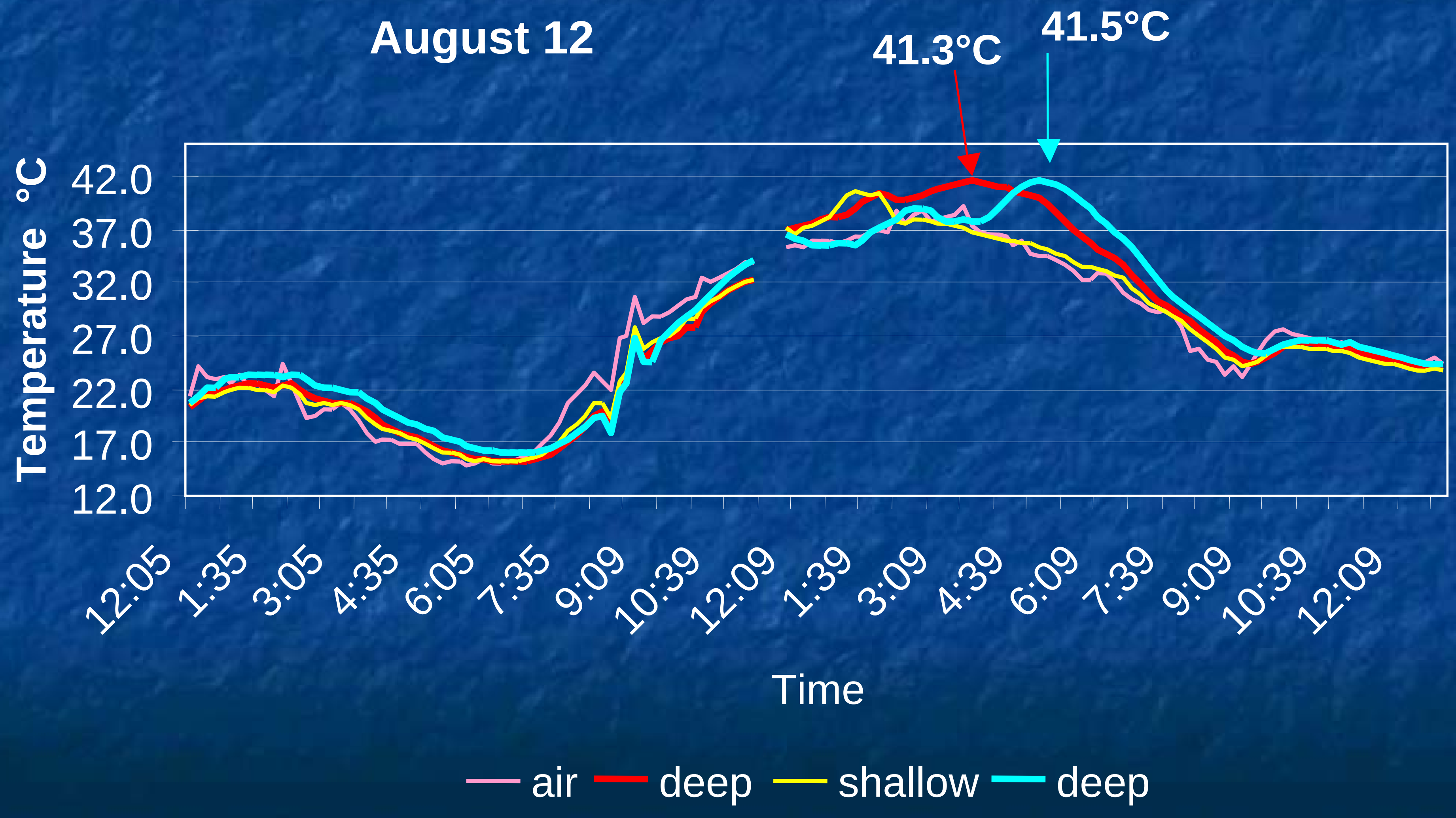




Effect of temperature cycling on the metabolic heat rate at 20 C of green peach aphids (*M. persicae*), expressed as a percentage of the original value, as a function of the stress temperature and number of cycles to the stress temperature.

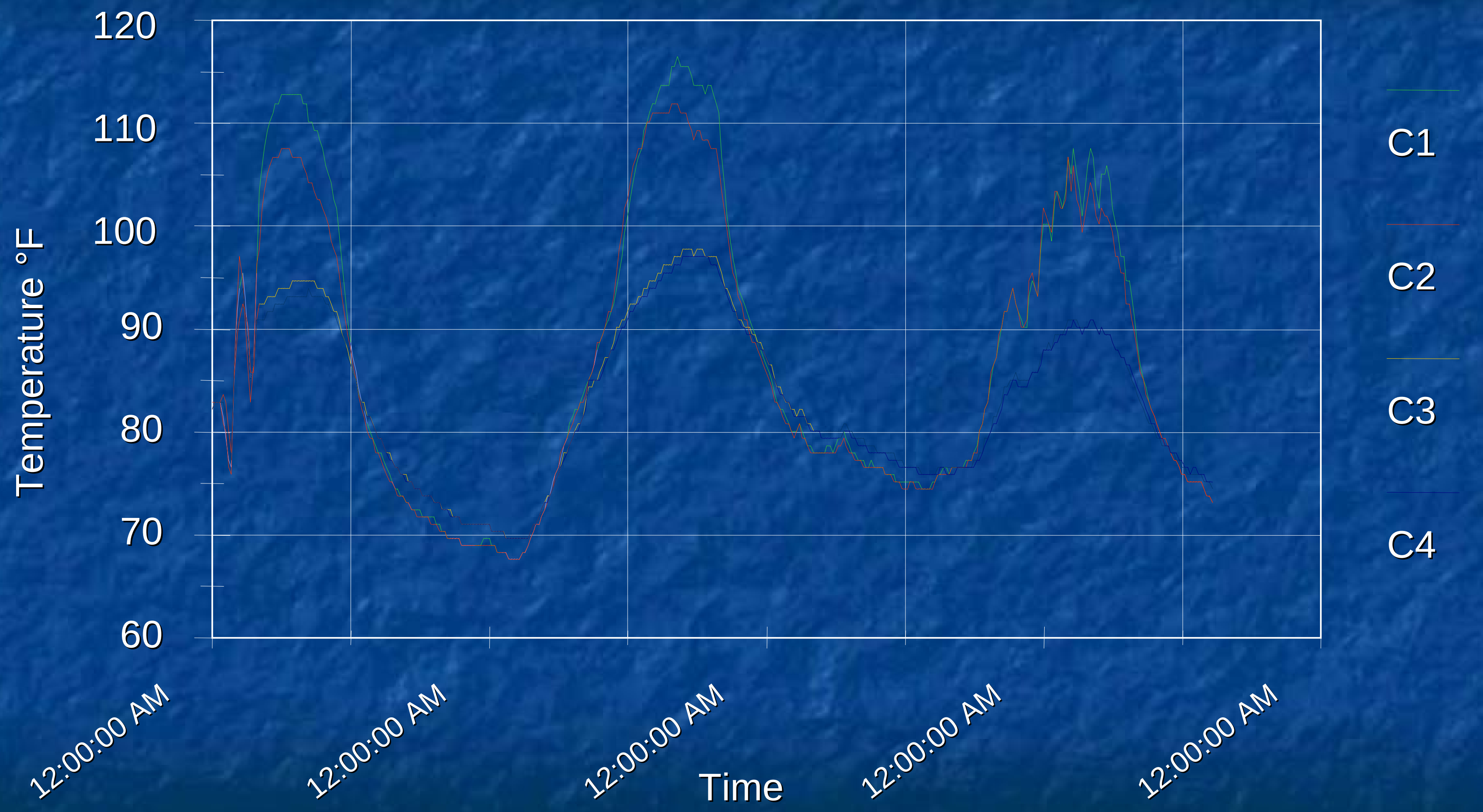
From: Downes et al. 2003.

Apple Temperatures During a Typical Summers' Day



Peach Fruit Temperatures

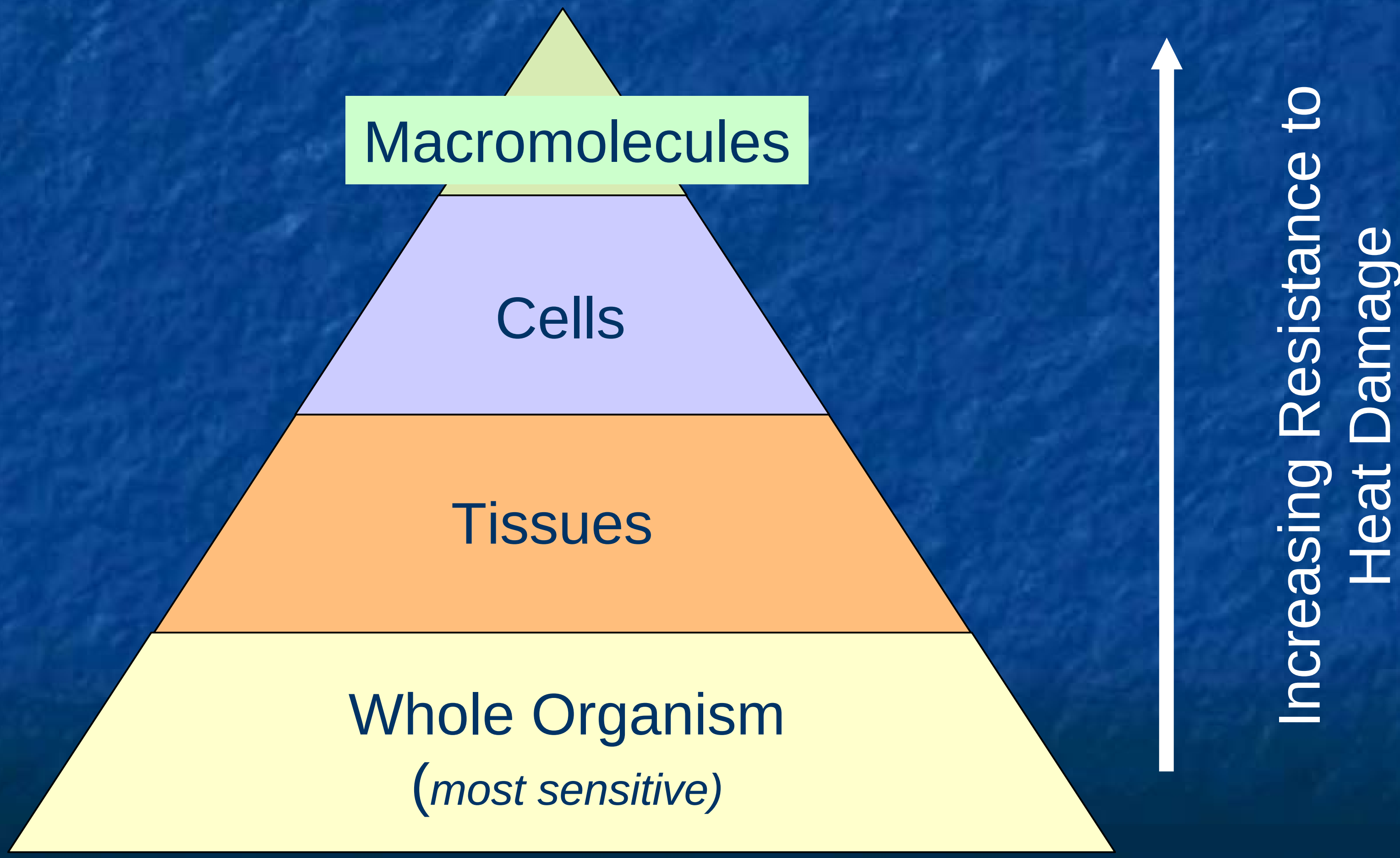
on the tree



MODELS OF THERMAL DAMAGE

- Roti Roti (1982) suggests that the effects of heat on macromolecules is the critical element of thermal damage.
- Bowler (1987) points to damage of the cell membrane as the critical event.

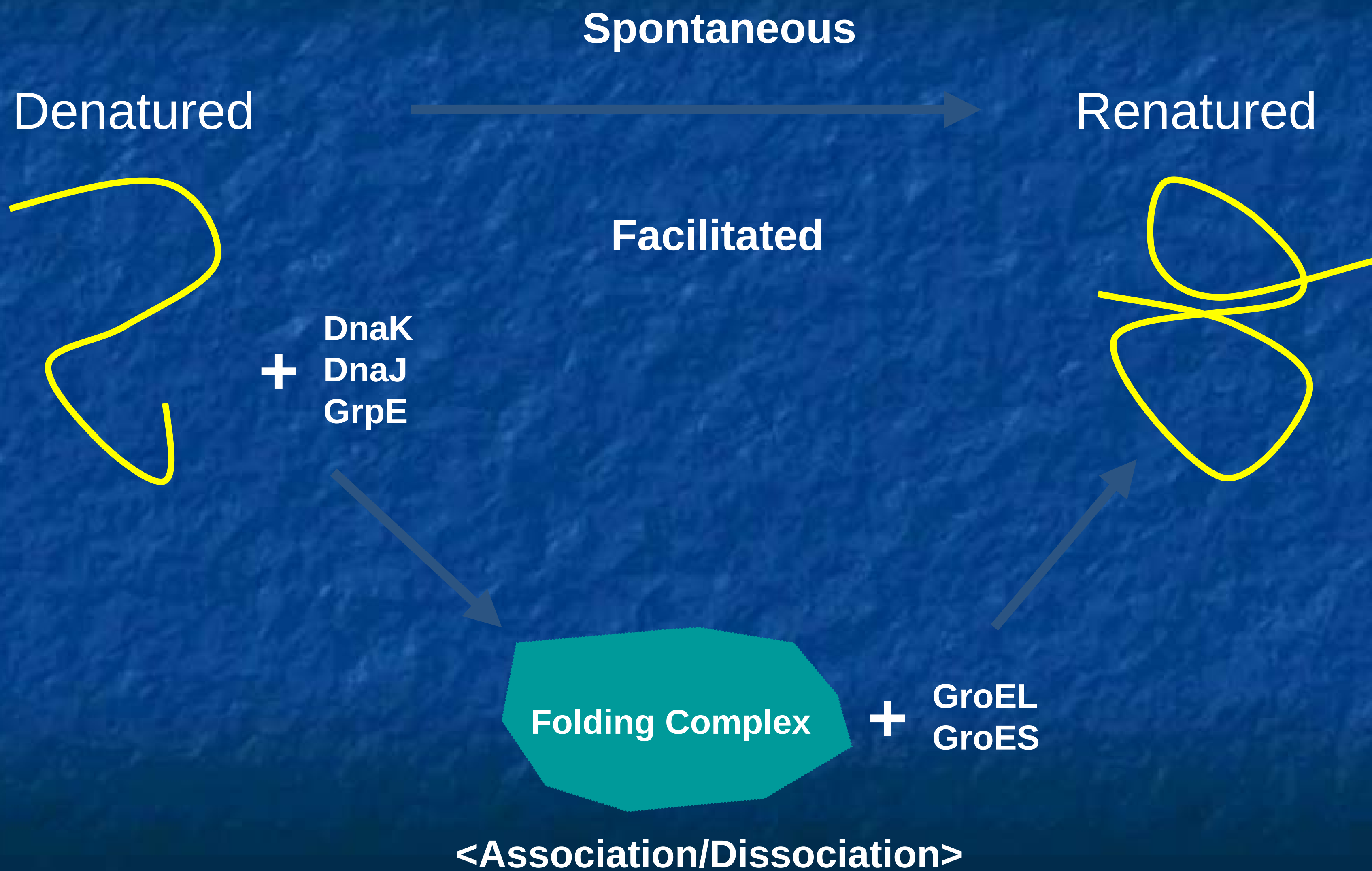
THERMAL DAMAGE:
It's a matter of Degrees



HEAT SHOCK PROTEINS

- Heat shock proteins are classified as to the molecular weight on SDS-PAGE.
- General classes:
  - low molecular weight 20-30 kDa
  - HSP70's—Most common in insects
  - HSP90's
  - HSP >100 kDa

HEAT SHOCK PROTEINS



Heat Rate and HSP's

- Thomas & Shellie 2000 described a reduction in the percent of Mexfly larvae expressing a HSP28 in relation to the rate of heating.
- The more rapid the rate of heating, the lower the percentage of the larvae expressing this HSP.

Heat Shock Proteins and Anoxia

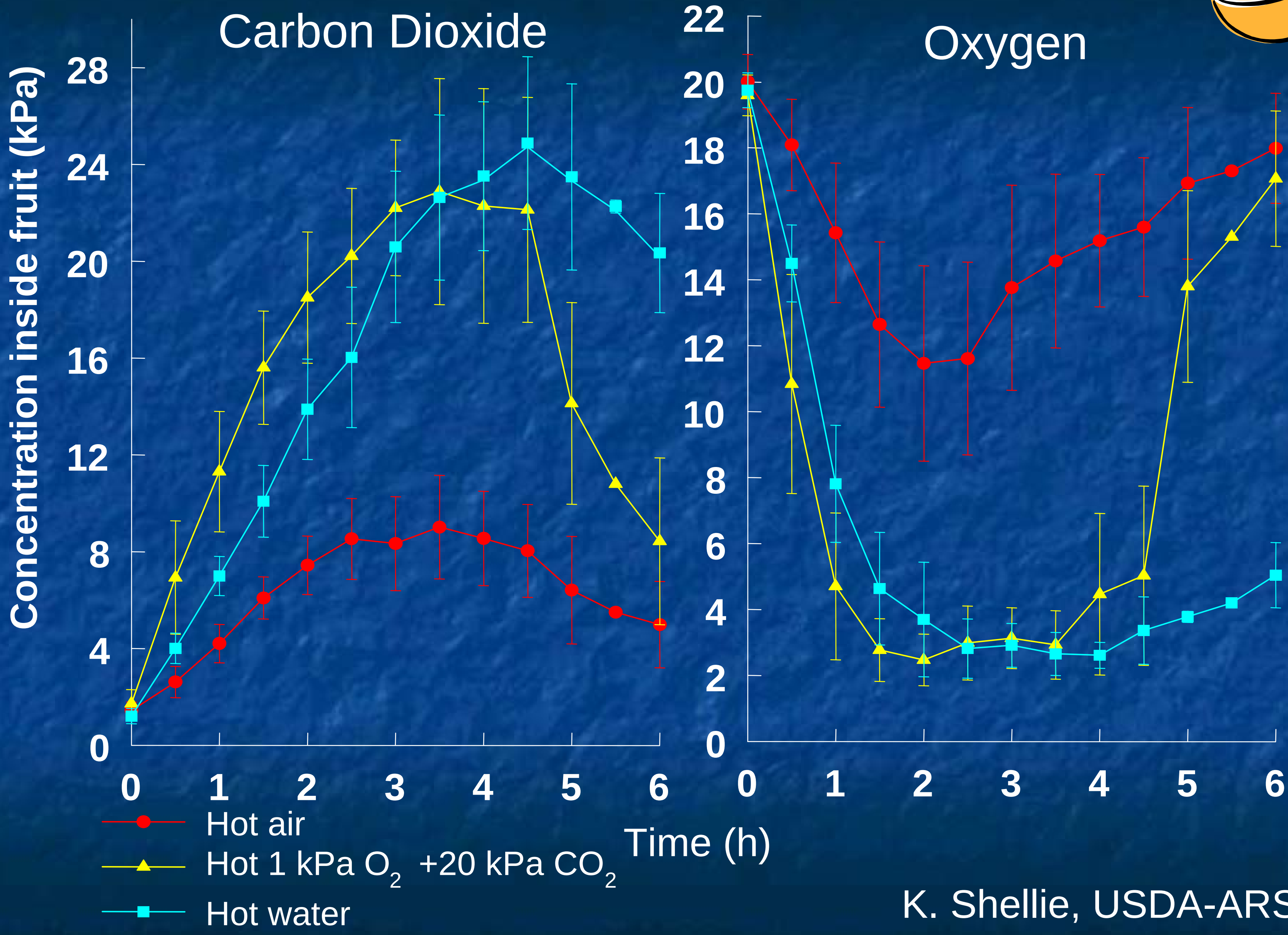
- The production of heat shock proteins in insects is inhibited under anoxic conditions. (Yocum & Denlinger 1994).

Types of CA Treatments

- Low Temperature CA:
  - 0-15°C, 0-5% O_2, 0-10% CO_2. Long duration.
- High Temperature CA:
  - 20-50°C, 0-5% O_2, 0-60% CO_2. Short duration.
- MAP (Modified Atmosphere Packaging):
  - 0-20°C, 1-18% O_2, 0-10% CO_2. Long Duration
- Film Wraps:
  - 20-27°C, variable ATM, long duration.
- Coatings:
  - 0-50°C, variable ATM, short or long duration. ?!?
- Hot Water Dips:
  - 42-55°C, 1-10% O_2, 0-10% CO_2. Short Duration.

Coating or Film?

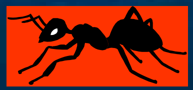
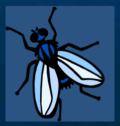
Isothermal Heat Doses



K. Shellie, USDA-ARS

CA Mode of Action on Insects

- >10% CO_2 stops production of NADPH which aids in detoxification
- Energy charge is reduced, slowing processes requiring ATP.
- Production of glutathione (used in MeBr detoxification) is reduced.
- High CO_2 inhibit regeneration of choline to acetylcholine.


Friedlander 1983.

CA and Metabolic Heat Rate

- Decrease in heat rate with decreasing O_2.
- Critical O_2 levels (P_c) increased with temp.
- Metabolic heat rate decreased rapidly at 20% CO_2, but little change up to 79%.
- Additive effects realized at $\leq$5% CO_2 and $\geq$4% O_2.
- High susceptibility to CO_2 at high temps. related to high metabolic heat rates.
- Low O_2 response correlated to metabolic arrest and anaerobic metabolism.

Zhou et al. 2000

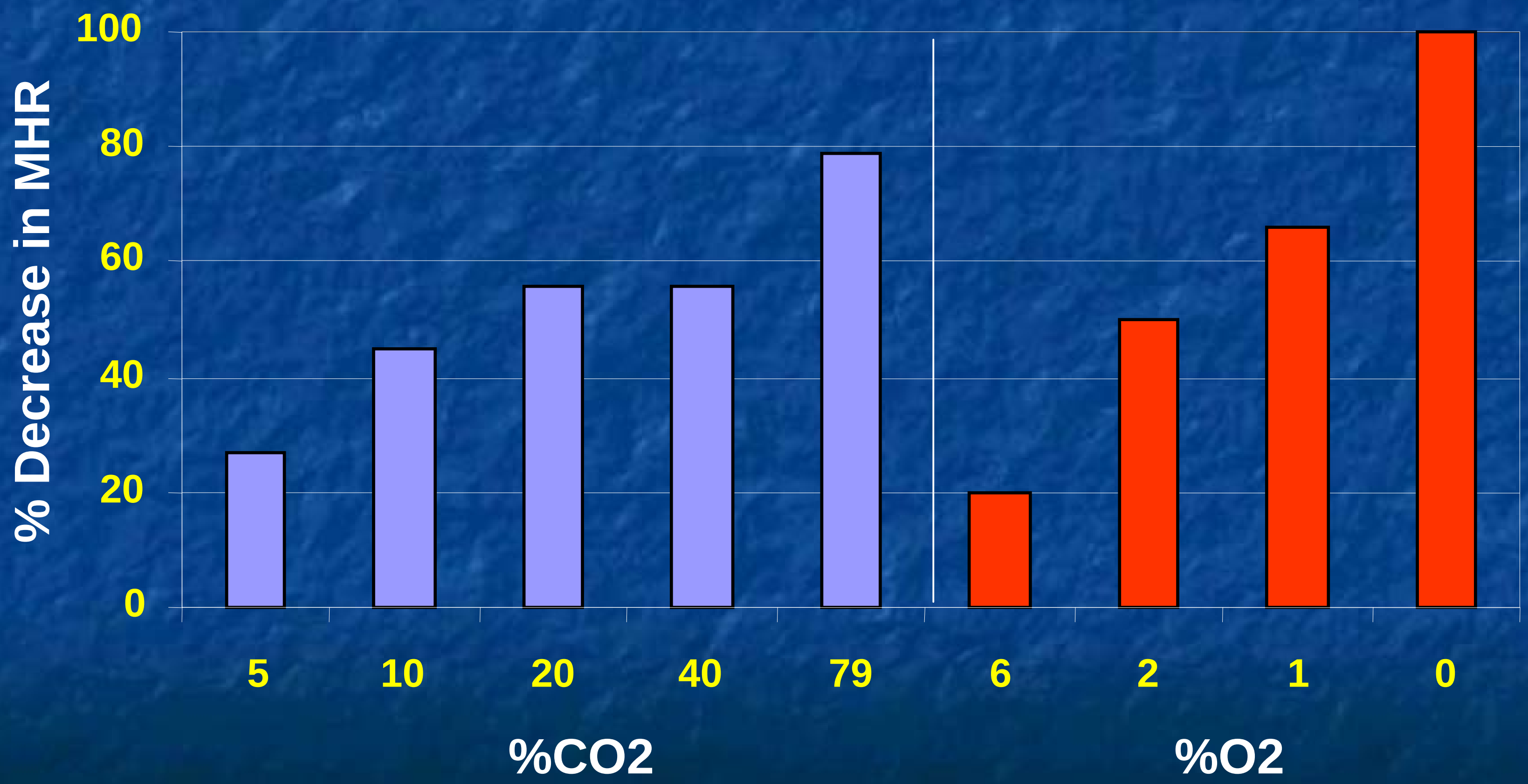
CA and Metabolic Response

- Decrease in MHR with increasing CO_2 and decreasing O_2.
- Recovery by pupae when MHR reduced by 30%.
- MHR decrease by 50% resulted in death.
- Mortality equivalent between 5% CO_2 and 6% O_2, and 10% CO_2 and 2% O_2.
- Effects of low O_2 and elevated CO_2 on membrane permeability.

Zhou et al. 2001

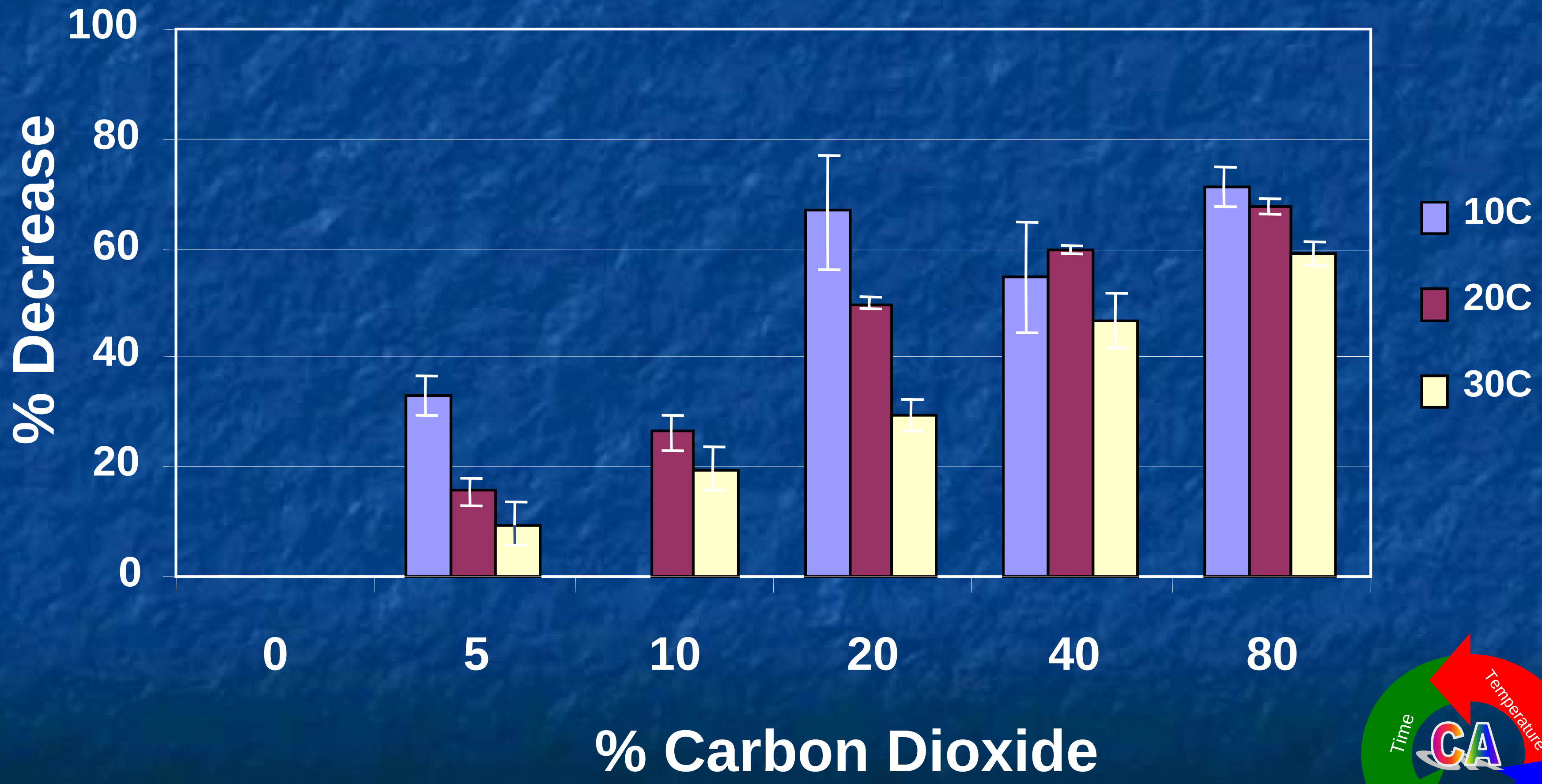
% Decrease in Metabolic Heat Rate

Platyona stultana pupae

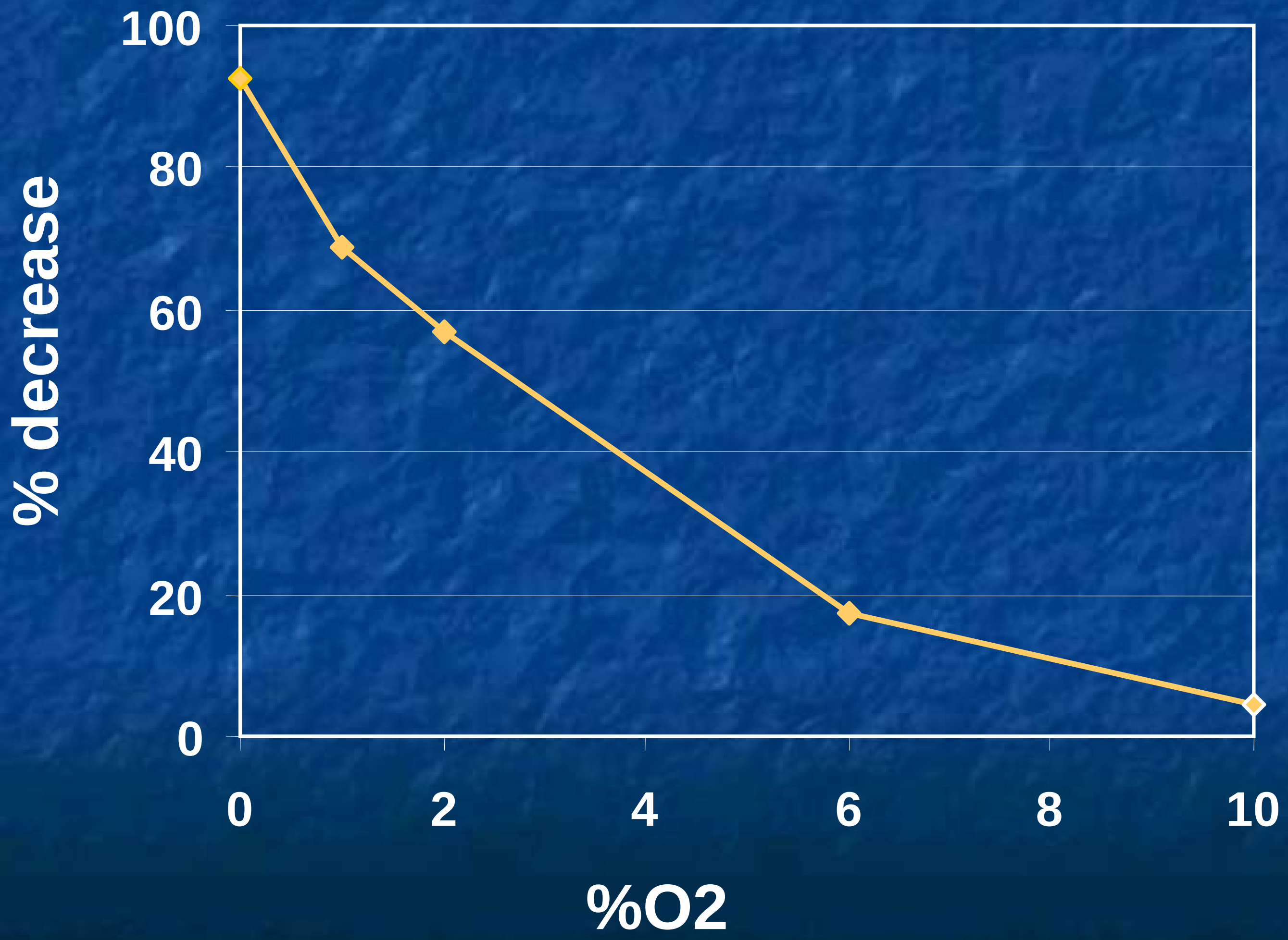


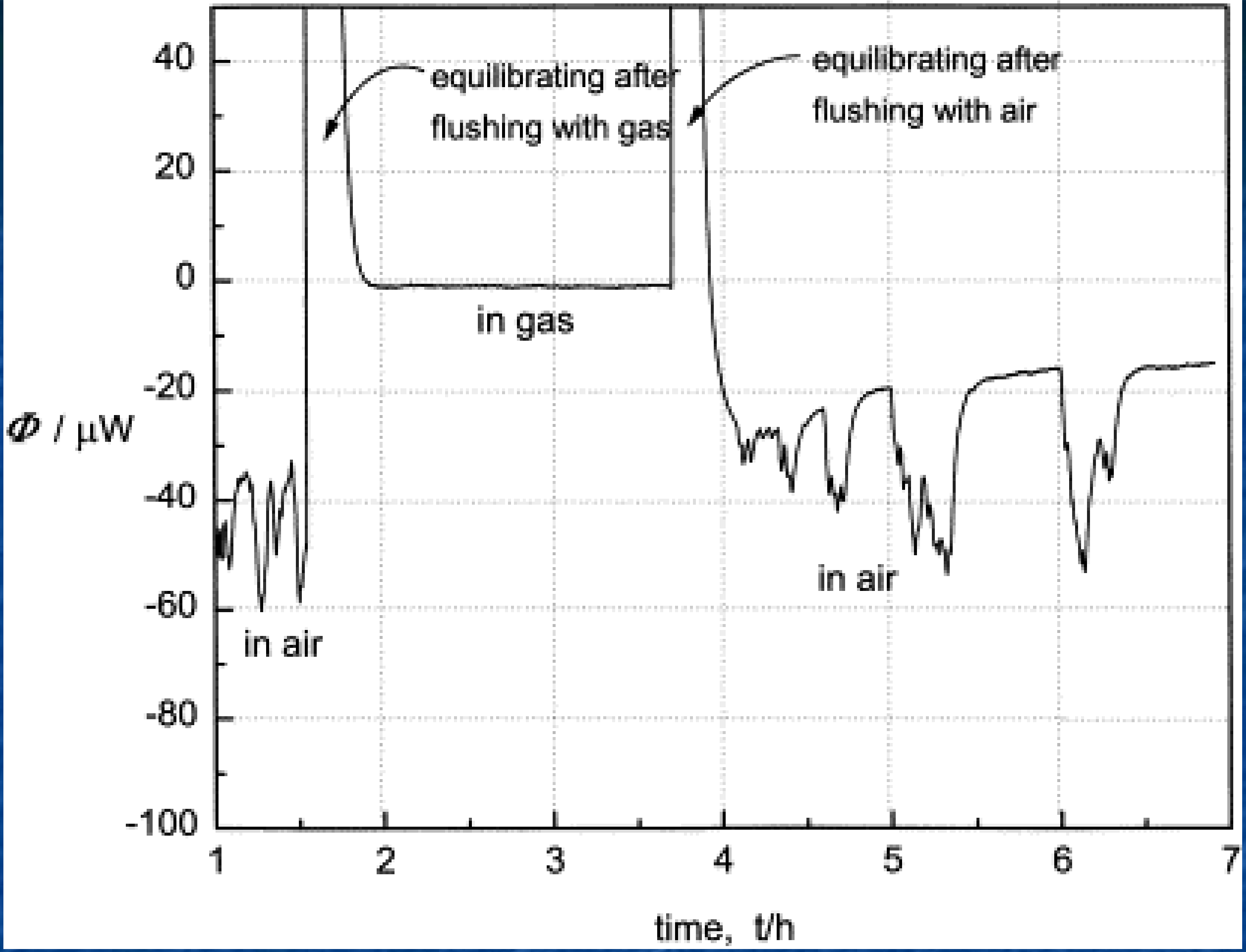
Zhou et al. 2001

% Decrease of Metabolic Rate of Codling Moth Pupae Under Varying Temperatures and Concentrations of Carbon Dioxide



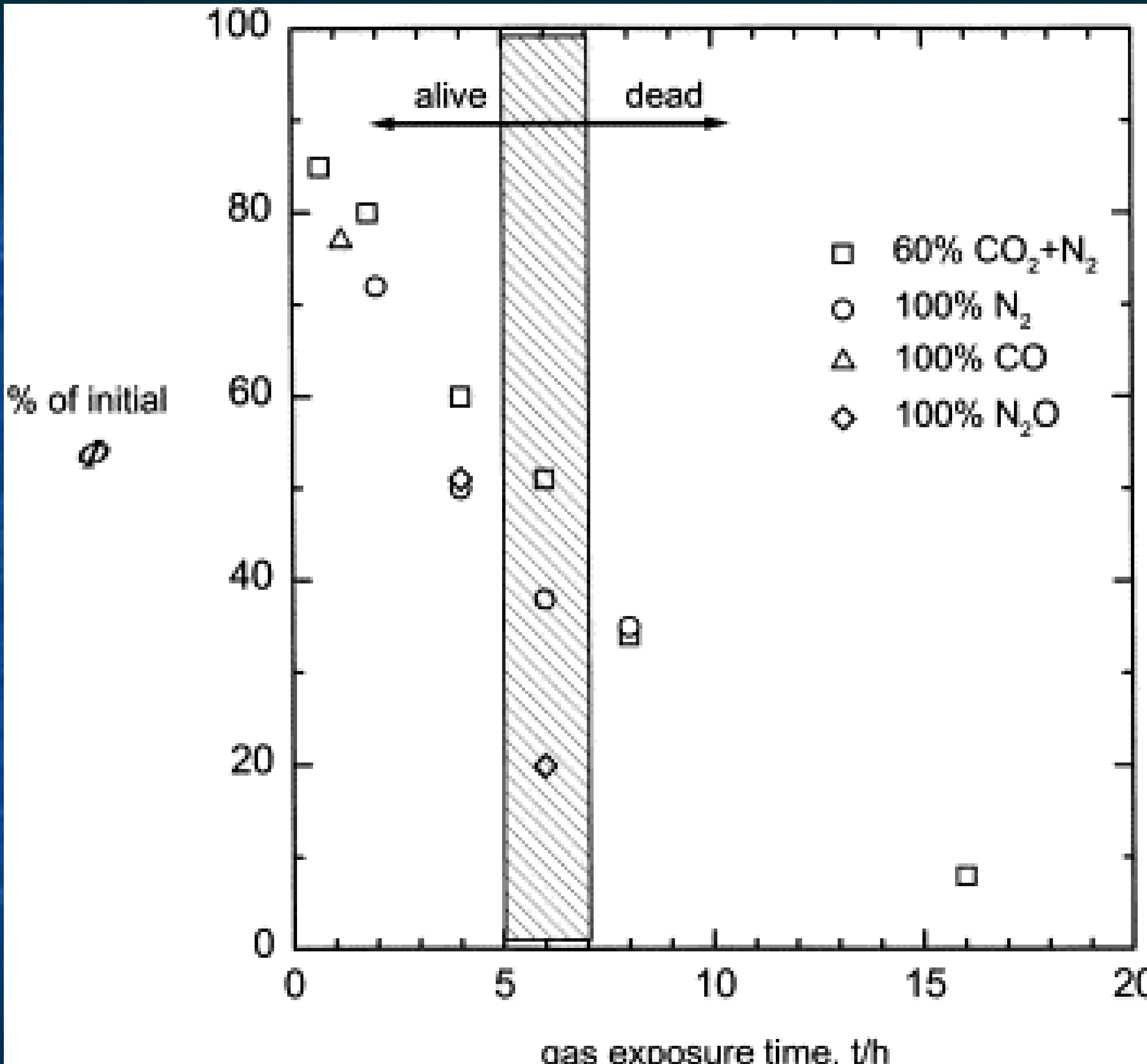
% Decrease of Metabolic Rate of Codling Moth Pupae Under Varying Concentrations of Oxygen





Metabolic heat rate at 20 °C of a codling moth (*C. pomonella*) pupa, fresh mass 0.0400 g, in air and in a controlled atmosphere of 60% CO_2 + N_2.

From: Downes et al. 2003.

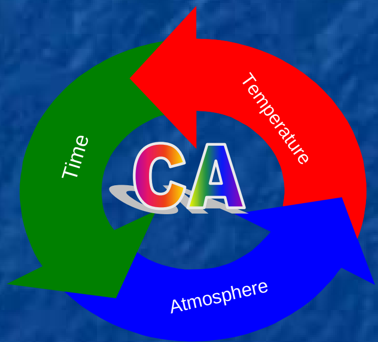


Response of green peach aphids (*M. persicae*) to anoxic atmospheres at 20°C, plotted as percent recovery of the initial metabolic heat rate in air, versus the time in the anoxic atmosphere.

Downes et al. 2003.

CATTS

Controlled
Atmosphere
Temperature
Treatment
System



Controls & Monitors:

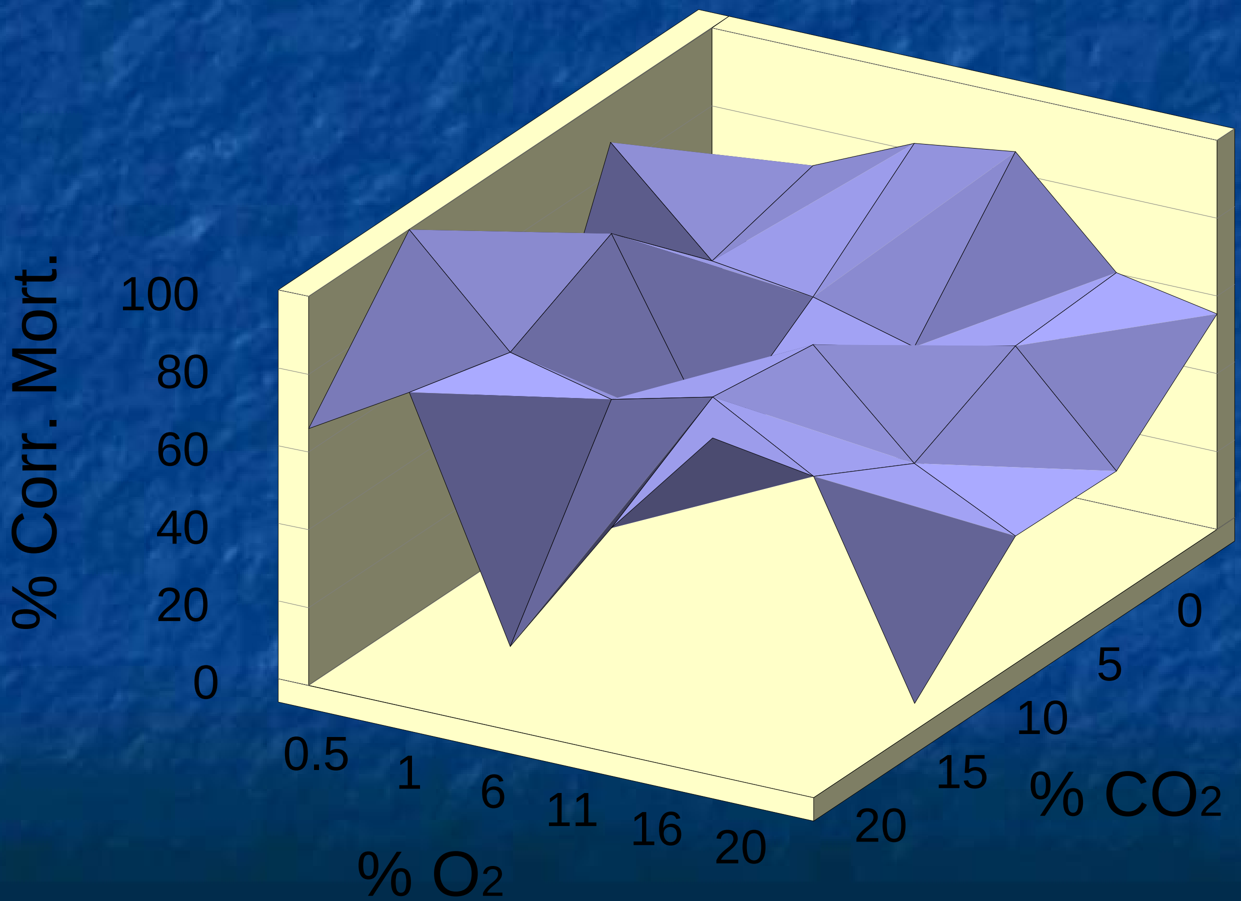
O_2, CO_2, Air Speed, Humidity, Dew Point, Air Temperatures, Heat Rate, Fruit Temperatures (surface & core)

Combined Effects of Oxygen and Carbon Dioxide Levels

- To determine the critical levels of O_2 and CO_2 needed to make a heat treatment most effective.
- Used optimized CATTS treatment times of 45 min for 45°C and 25 min for 47°C (at 1%O_2 and 15%CO_2) as end points.
- 5 Levels of CO_2 and 6 levels of O_2.
- 50 larvae per time point per rep. (4 reps).

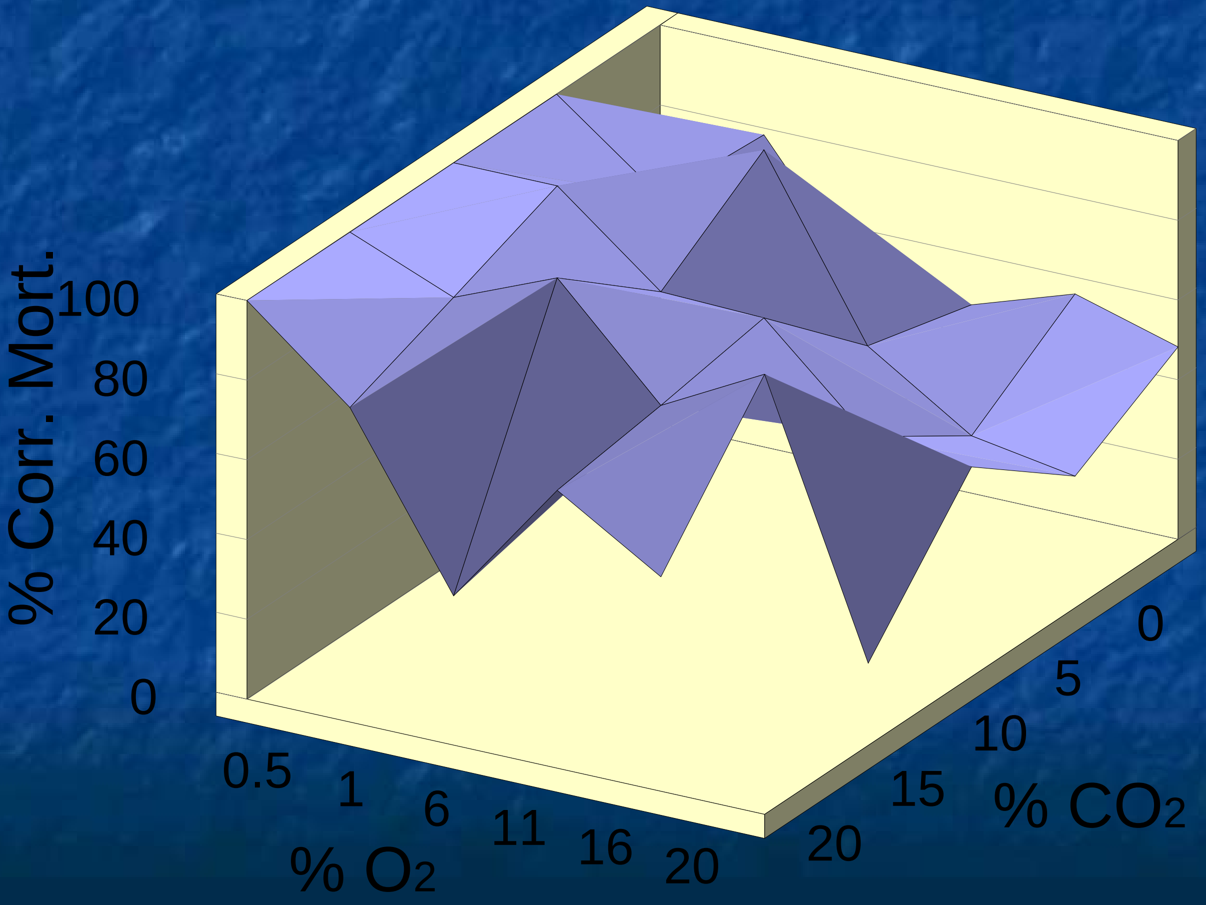
45°C, 20 min

3rd instar codling moth in sweet cherries



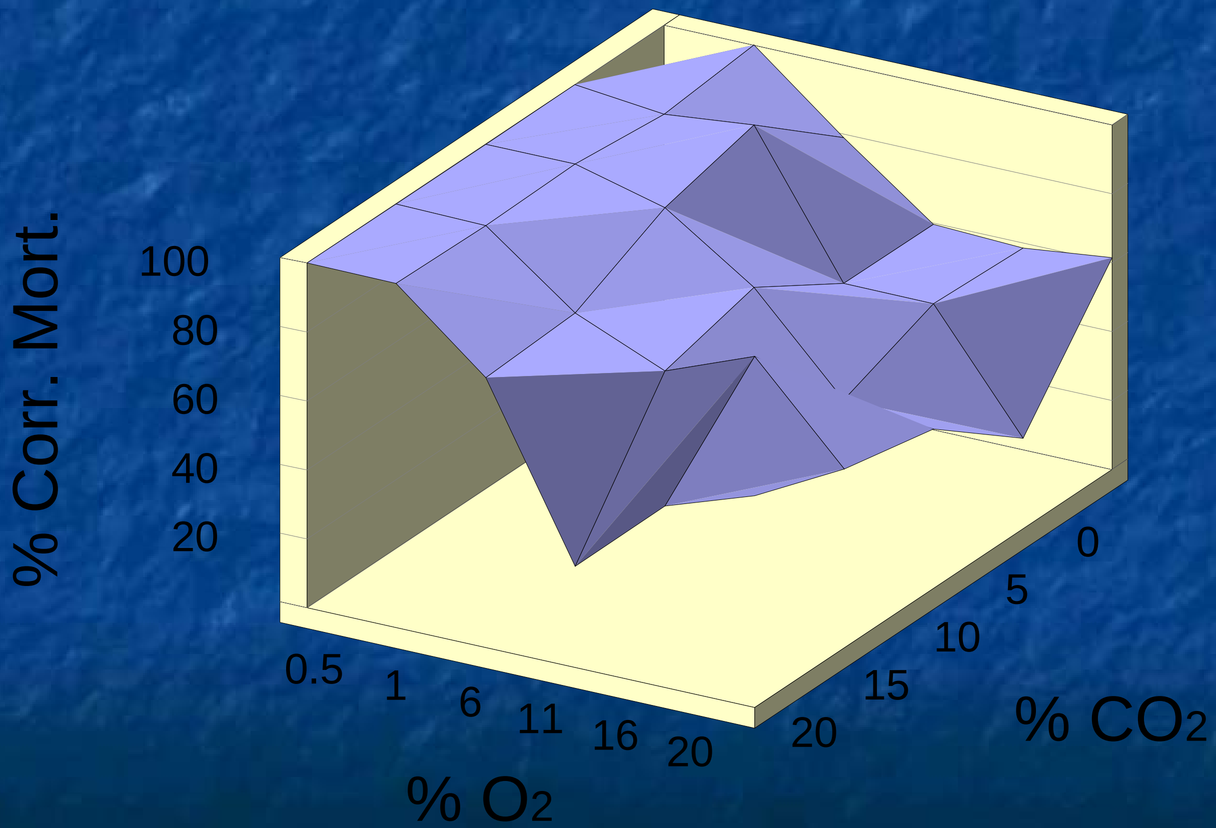
45°C, 30 min

3rd instar codling moth in sweet cherries



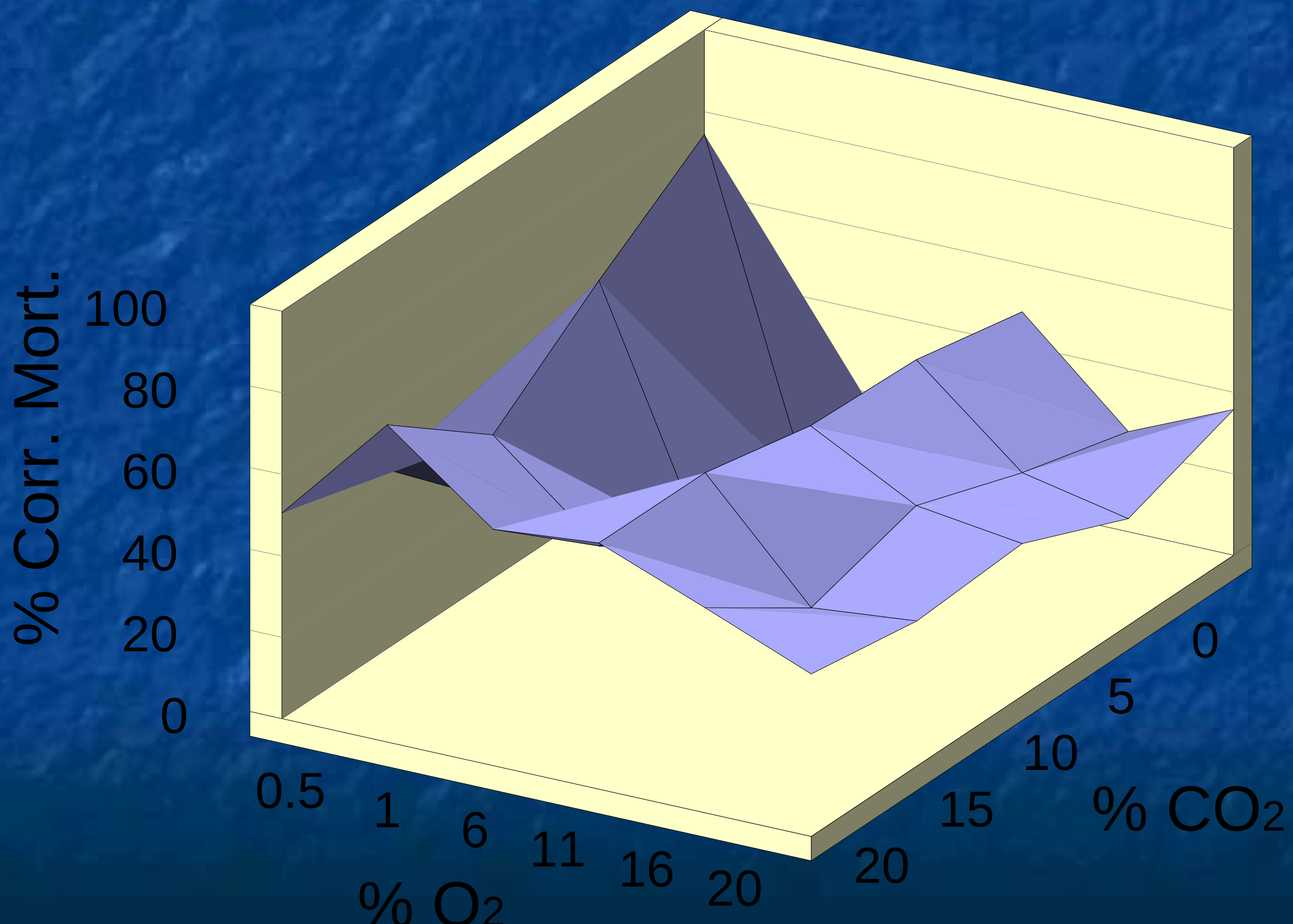
45°C, 40 min

3rd instar codling moth in sweet cherries



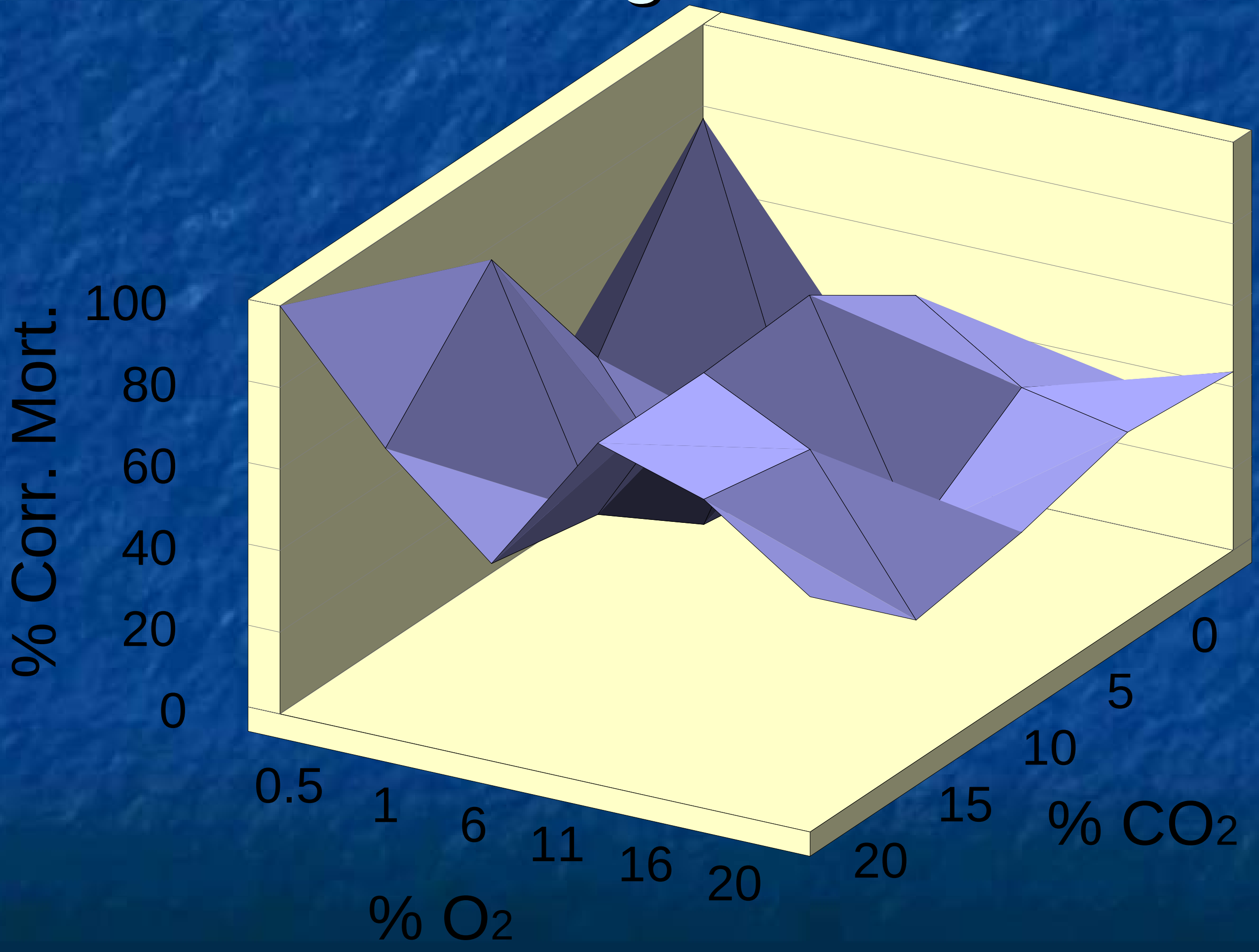
47°C, 10 min

3rd instar codling moth in sweet cherries



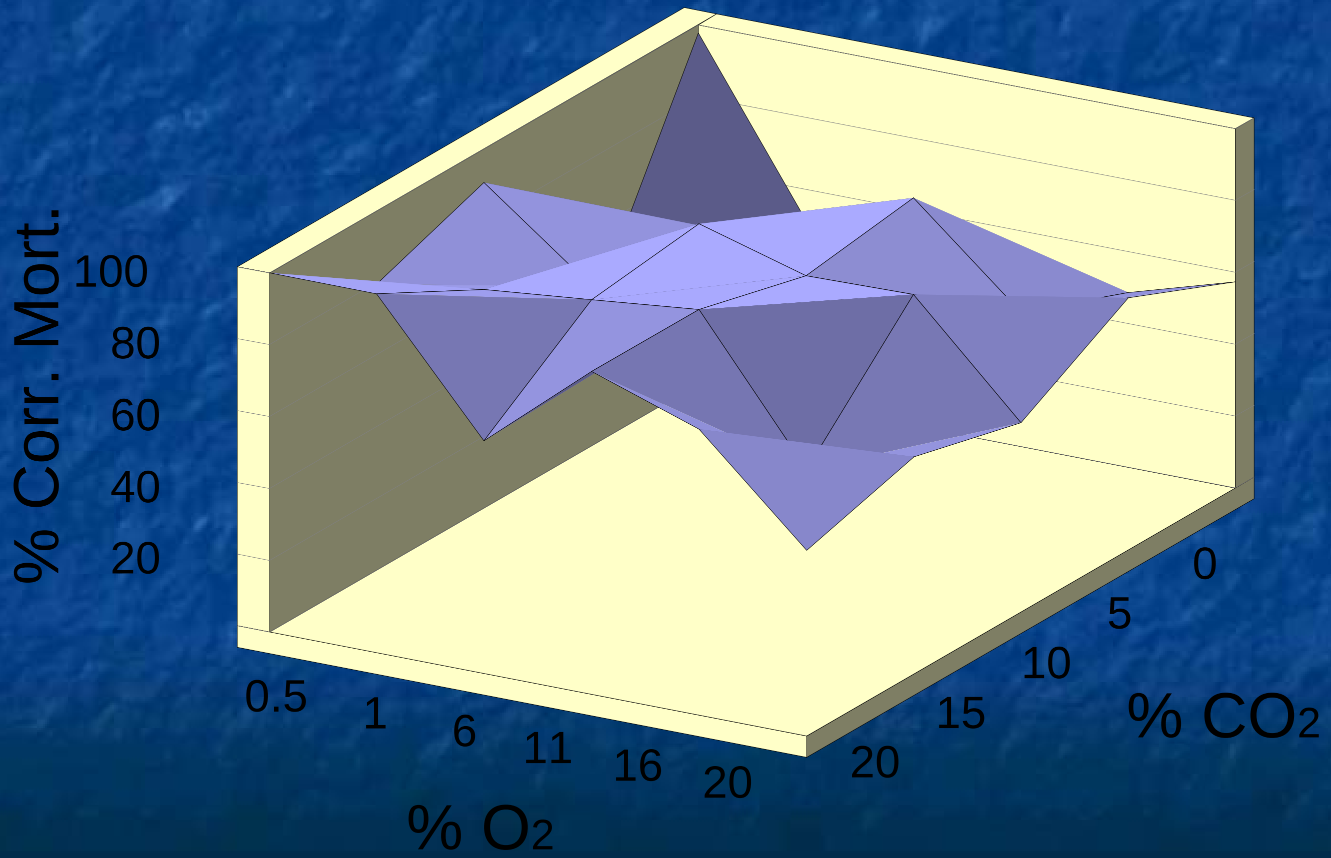
47°C, 15 min

3rd instar codling moth in sweet cherries



47°C, 20 min

3rd instar codling moth in sweet cherries

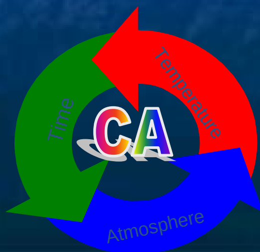


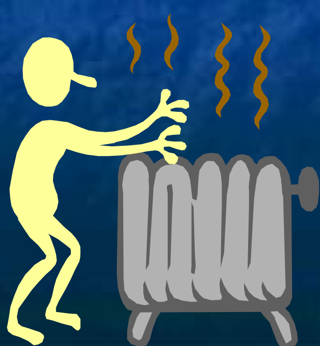
Summary O_2/CO_2 Study

- Low oxygen, between 0.5 and 1.0% proved to be most critical in providing efficacy.
- High levels of carbon dioxide, were less effective in causing mortality, but still necessary for treatment efficacy.

Making CA More Effective

- Heat shock before cold CA may protect commodity from chilling injury.
- Short heat treatment with CA can be very effective for disinfestations.
- Raising temperature a couple of °C with low O_2 and elevated CO_2 can help.
- Lengthen duration of CA storage.

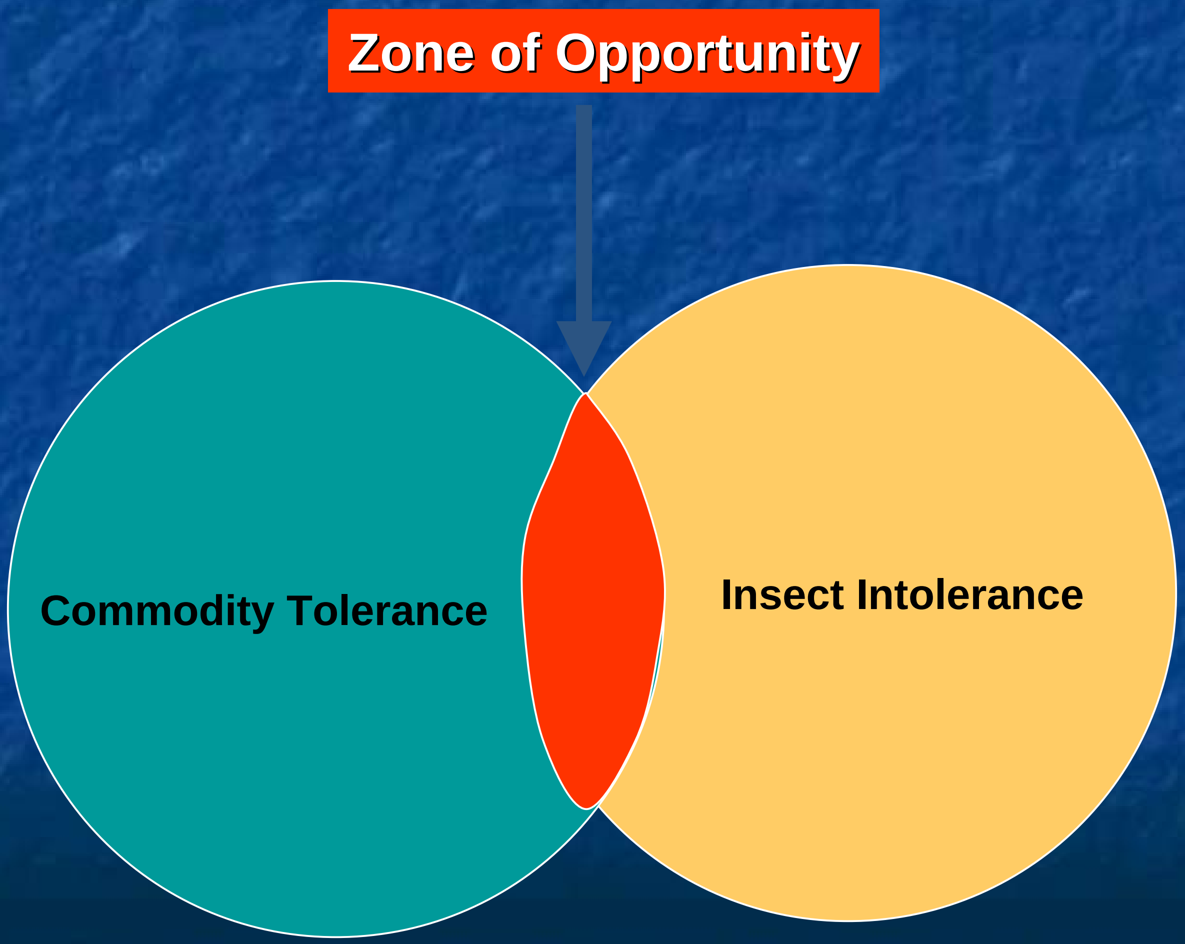




Summary

- Effects of physical treatments on insects is as varied as the treatments themselves.
- For many treatments, the affected systems are variable, and may depend on how scientists chose to look at the effects.
- The key to developing physical quarantine treatments is to pinpoint the physiological weakness of the insect or the physiological differences between the horticultural commodity and the infesting insect.

Goal for Development of Physical Postharvest Quarantine Treatments



Special Thanks!

James Hansen

Elizabeth Mitcham

Krista Shellie

Stan Ignatowicz

Guy Hallman

Jumming Tang

Shaojin Wang

Jim Mattheis

Positive proof that coatings do cause the formation of ‘modified atmospheres’ in humans!