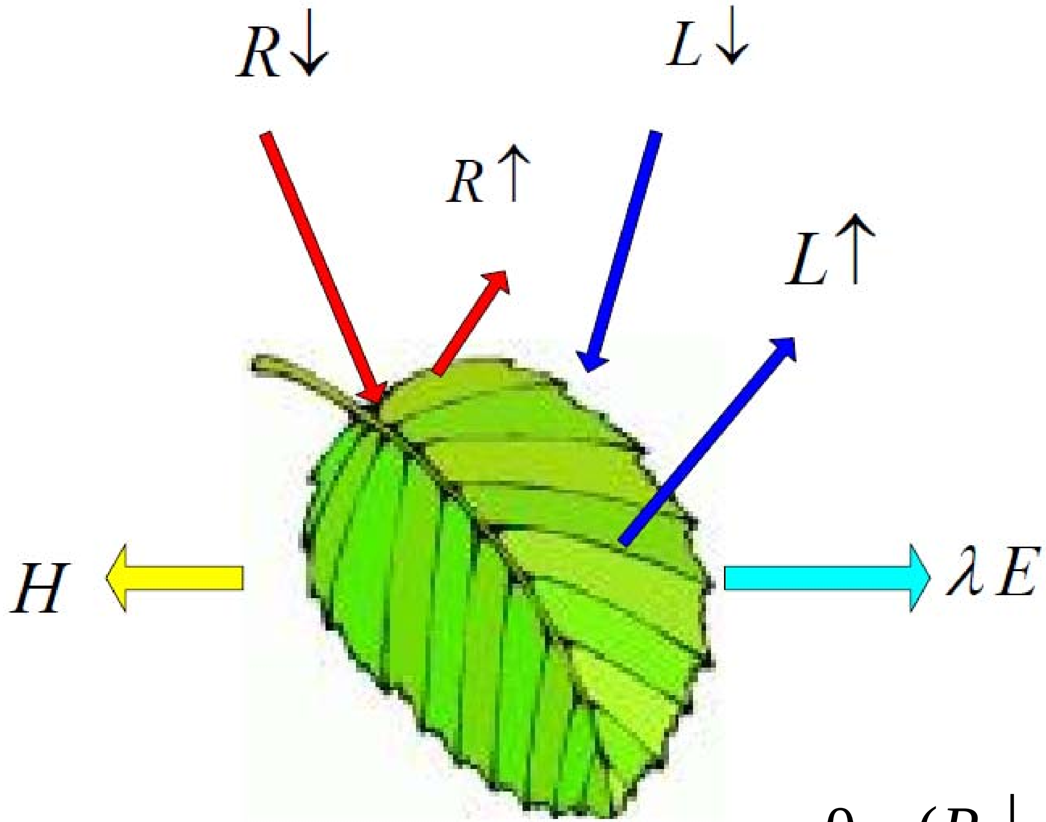
Ecophysiology

Please Note: Some of the slides are Animated and are best viewed as a Slide Show; some slides have attached notes below the slides and these are best viewed in Normal (editing) view.

6. Energy Budgets / Temperature

Energy Budgets

Leaf Energy Budget



R = Short-wave Radiation
(300 – 3000 nm)

L = Long-wave Radiation
(>3000 nm)

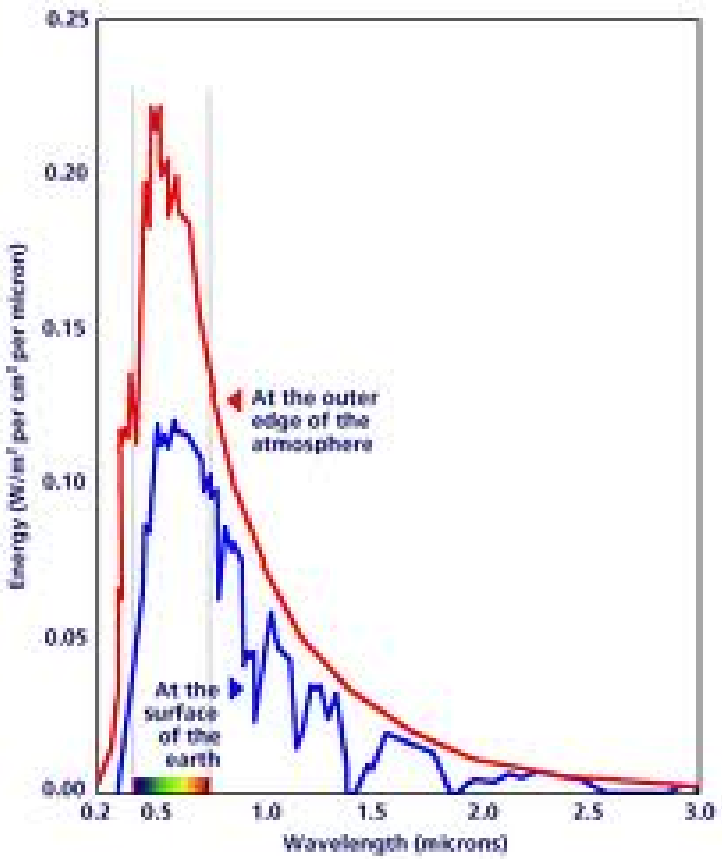
lE = Transpirational Cooling

H (or C) = Convection

At Equilibrium:-

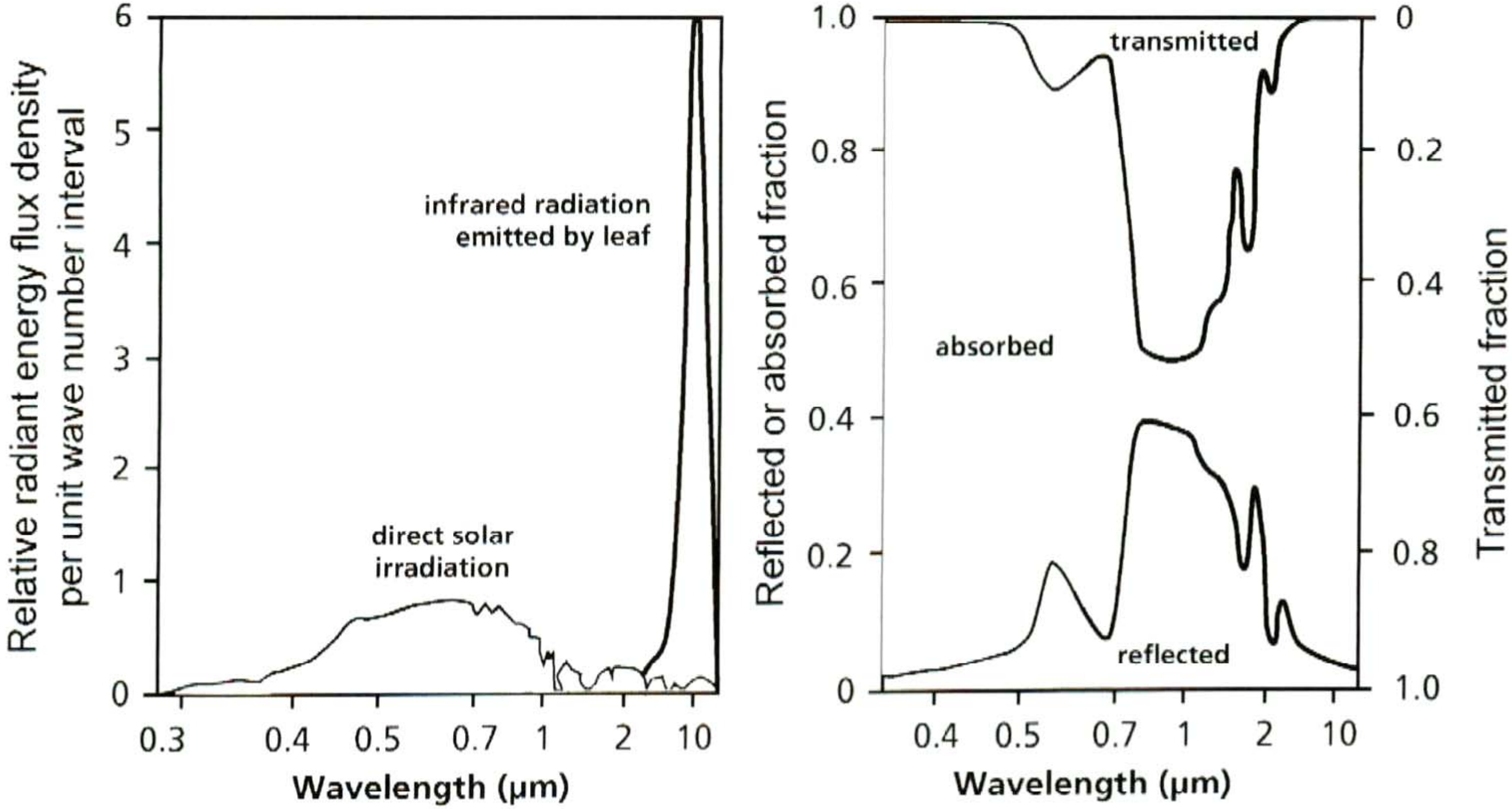
$$0 = (R\downarrow + R\uparrow) + (L\downarrow + L\uparrow) + H + \lambda E$$

Short-wave Radiation (300-3000 nm)

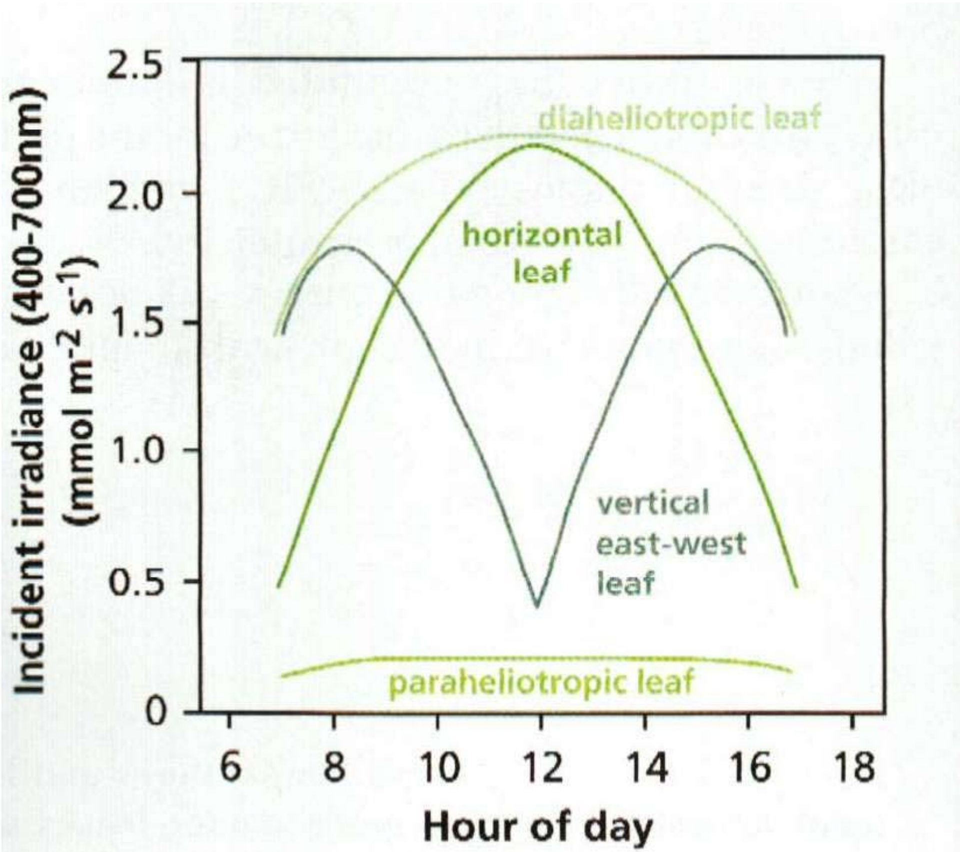


- >95% Sun's Energy
- ~50% in 400 – 700 nm range
- Leaf Absorbtance ~ 0.85
- SW IR (700-1200 nm) mostly reflected or transmitted
- SW IR (1200-3000 nm) absorbed by leaf water

The SR Spectrum



SR Interception by Leaves

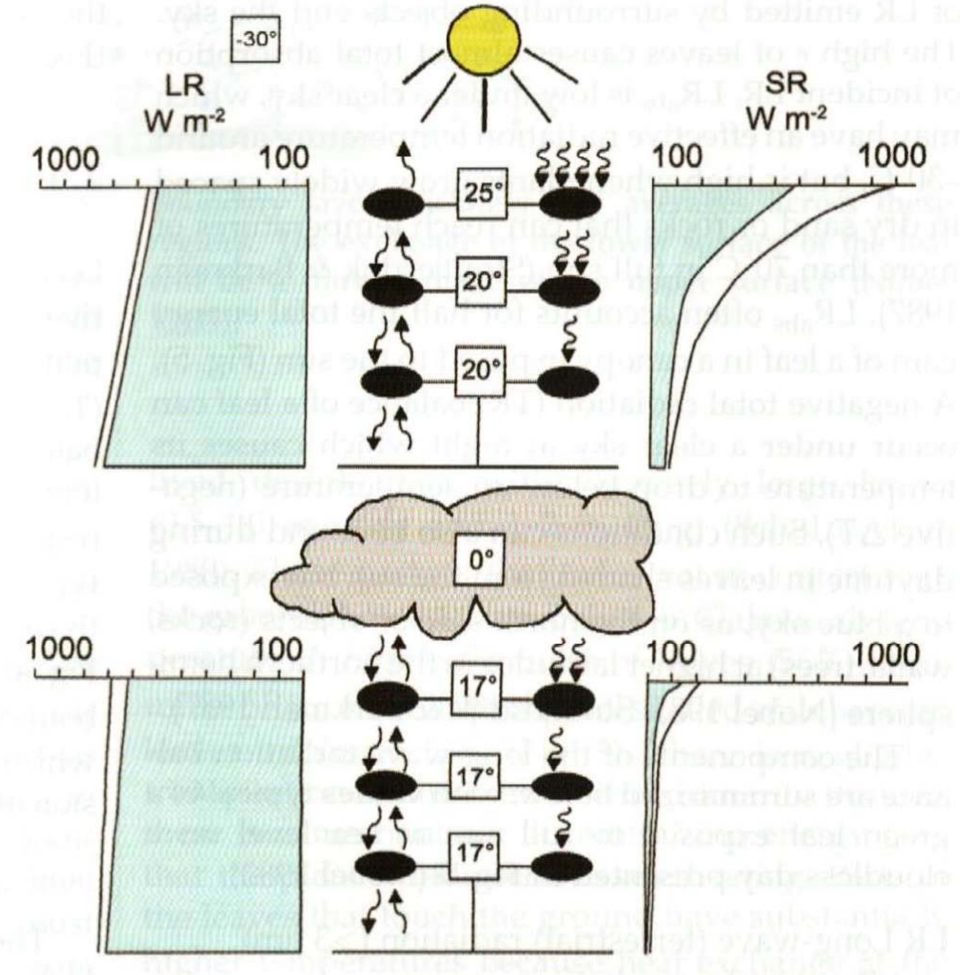


Diaheliotropic Responses in *Helianthus annus*

$$SR_{Abs} = SR_{in} - SR_{r} - SR_{tr}$$

$$SR_{Net} = SR_{abs} - SR_{Ass} - SR_{Flu}$$

LR & SR Energy Balance in a Canopy



On a cloudless day the sky has an apparent LR Temperature of -30C

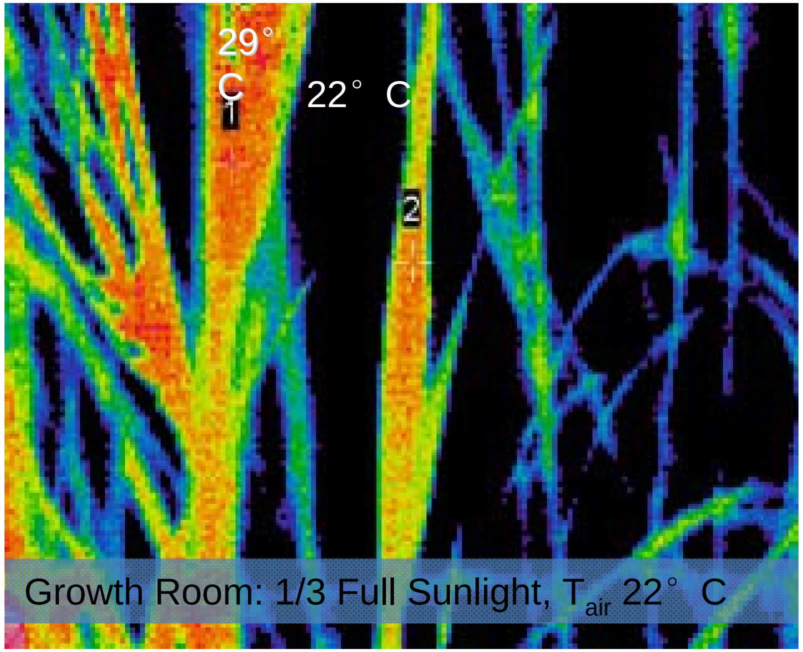
Plants gain a significant proportion of their heat from re-absorbed LR radiation ~50% on cloudy days

LR

Stefan's Law (Black Body Radiation)

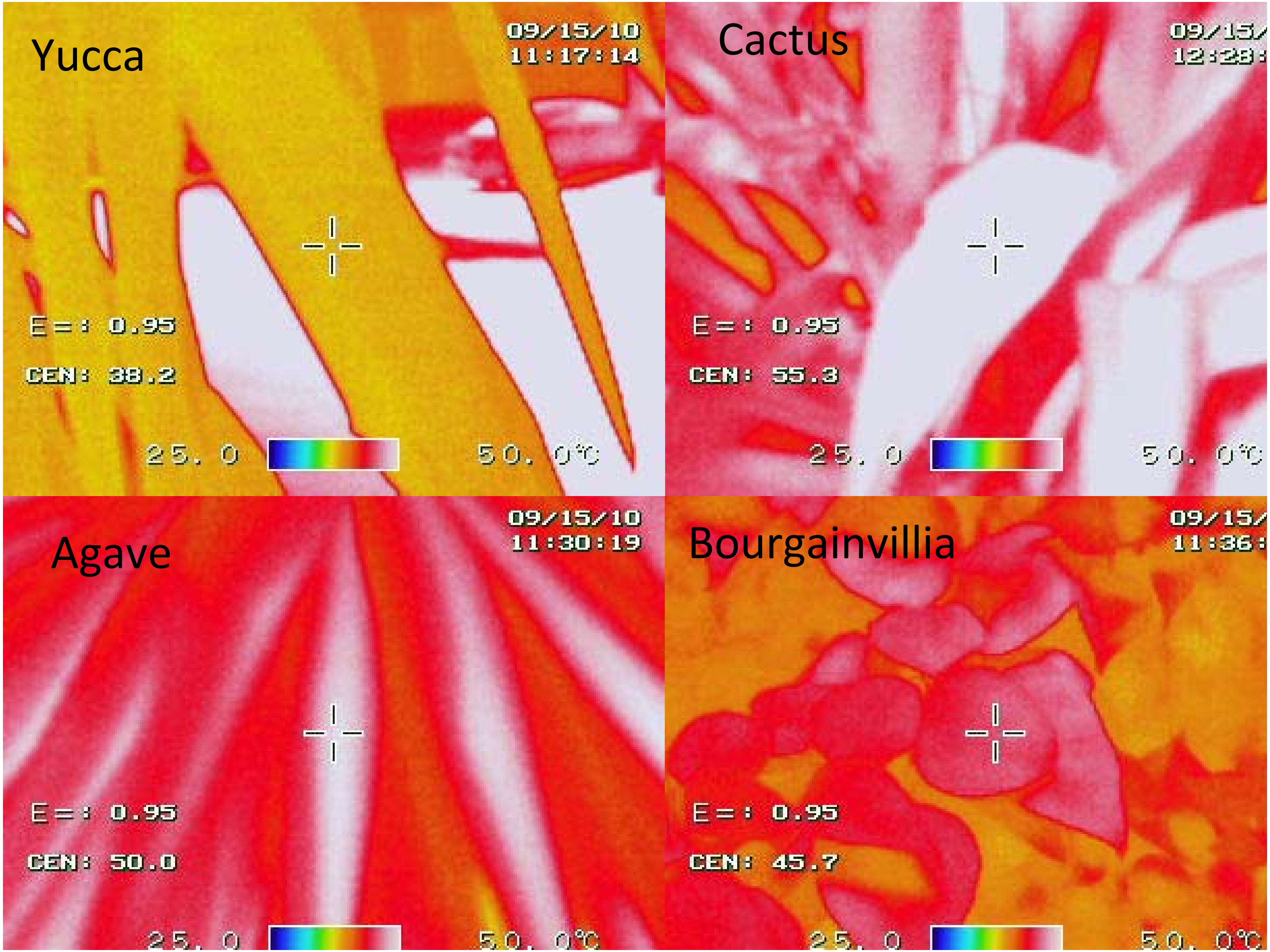
$$LR_{em} = \varepsilon\sigma T^{4}$$

e = Emissivity, typically 0.96 for leaf
s = Stefan-Boltzmann Constant
(5.57 . 10^{-8} W m^{-2} K^{-4})
T= temperature in Kelvin



A leaf gains ~ ½ its energy from LR

This is a Thermal Image (4.5 – 6.5 mm) of well-watered barley plants growing in a temperature controlled room. The leaf temperature is 7C above air temperature; what would the leaf temperature be if the air temperature was 35C and full sunlight was used?

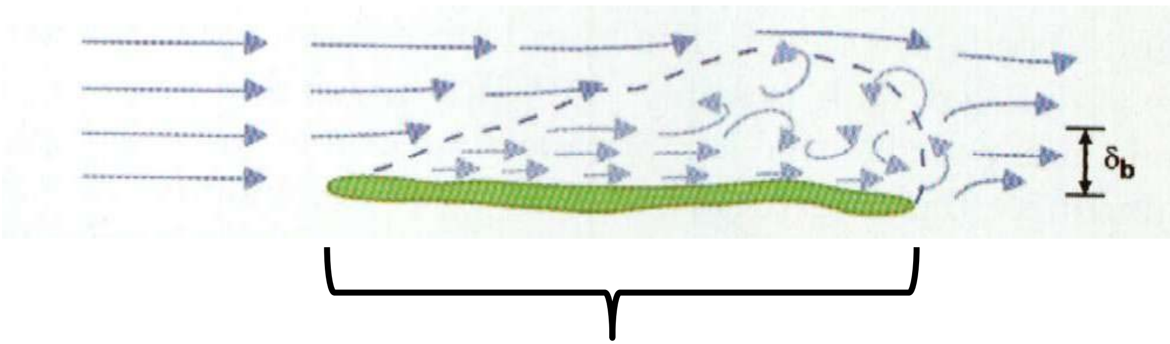

Yucca
09/15/10
11:17:14
E=: 0.95
CEN: 38.2
25.0
50.0℃
Cactus
E=: 0.95
CEN: 55.3
25.0
50.0℃
Agave
09/15/10
11:30:19
E=: 0.95
CEN: 50.0
25.0
50.0℃
Bourgainvillia
E=: 0.95
CEN: 45.7
25.0
50.0℃

Convective or ‘Sensible’ Heat Transfer

$$C = g_{ah}\left(T_a - T_L\right)$$

T_a = Temperature of Air
T_L = Temperature of Leaf
g_{ah} = boundary layer conductance

g_{ah} is Inversely Proprotional to Boundary Layer Thickness (d) and Wind Speed (u)
d is the Width of Leaf



$$\delta = 4\sqrt{d/u}$$

d

Small Leaves Convect Heat Better than Large Leaves

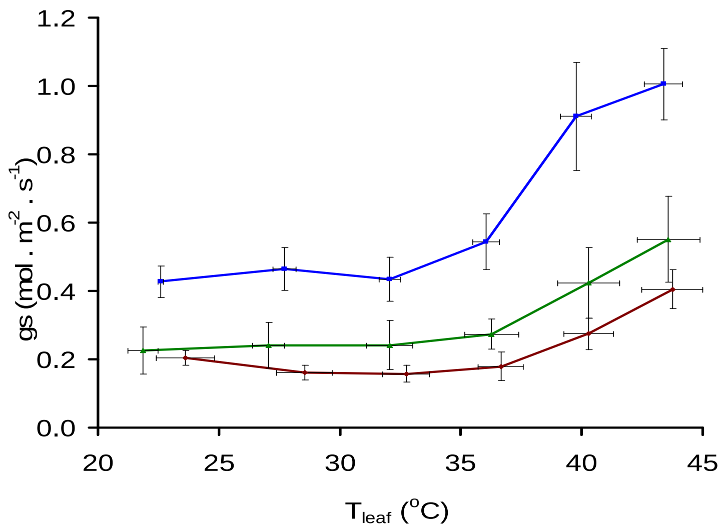
Evaporative Energy Exchange: Transpiration

$$\lambda E = -\lambda g_w (e_{in} - e_{air})$$

e_{in} = humidity inside leaf
e_{air} = humidity in air
$g_w = g_s + g_b$ stomatal & boundary layer conductances
l = latent heat of vaporization (2450 J g^{-1})

"A popular but incorrect idea is that plants control their leaf temperature by regulating transpiration". Lambers *et al.* 2008

...but stomata open when T_{leaf} rises above 35C!



High Light - Excess Light is Dissipated

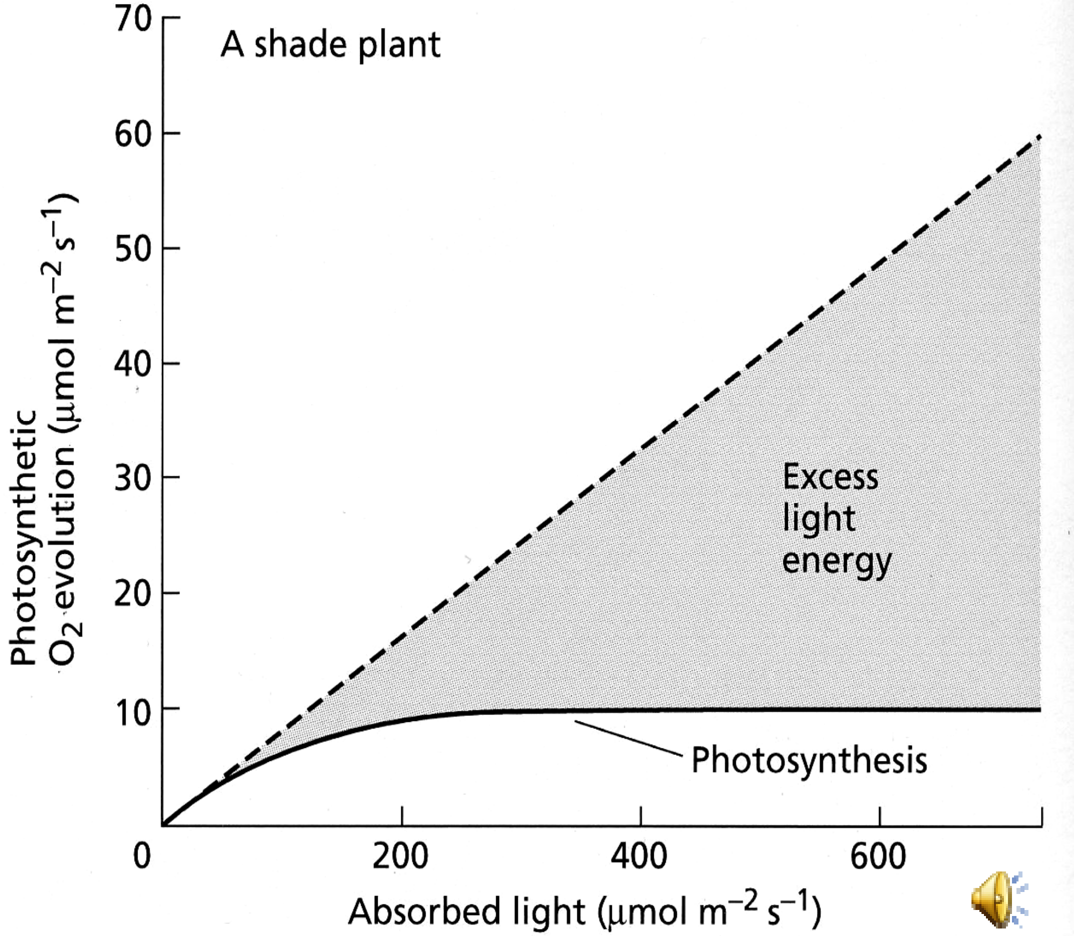
Too Much Light Can Cause the Production of Excessive Levels of $^1O_2$
⇨ other ROSs (O^-_2, $^*OH^-$, etc.)

⇨Photo-Oxidation (Photobleaching)

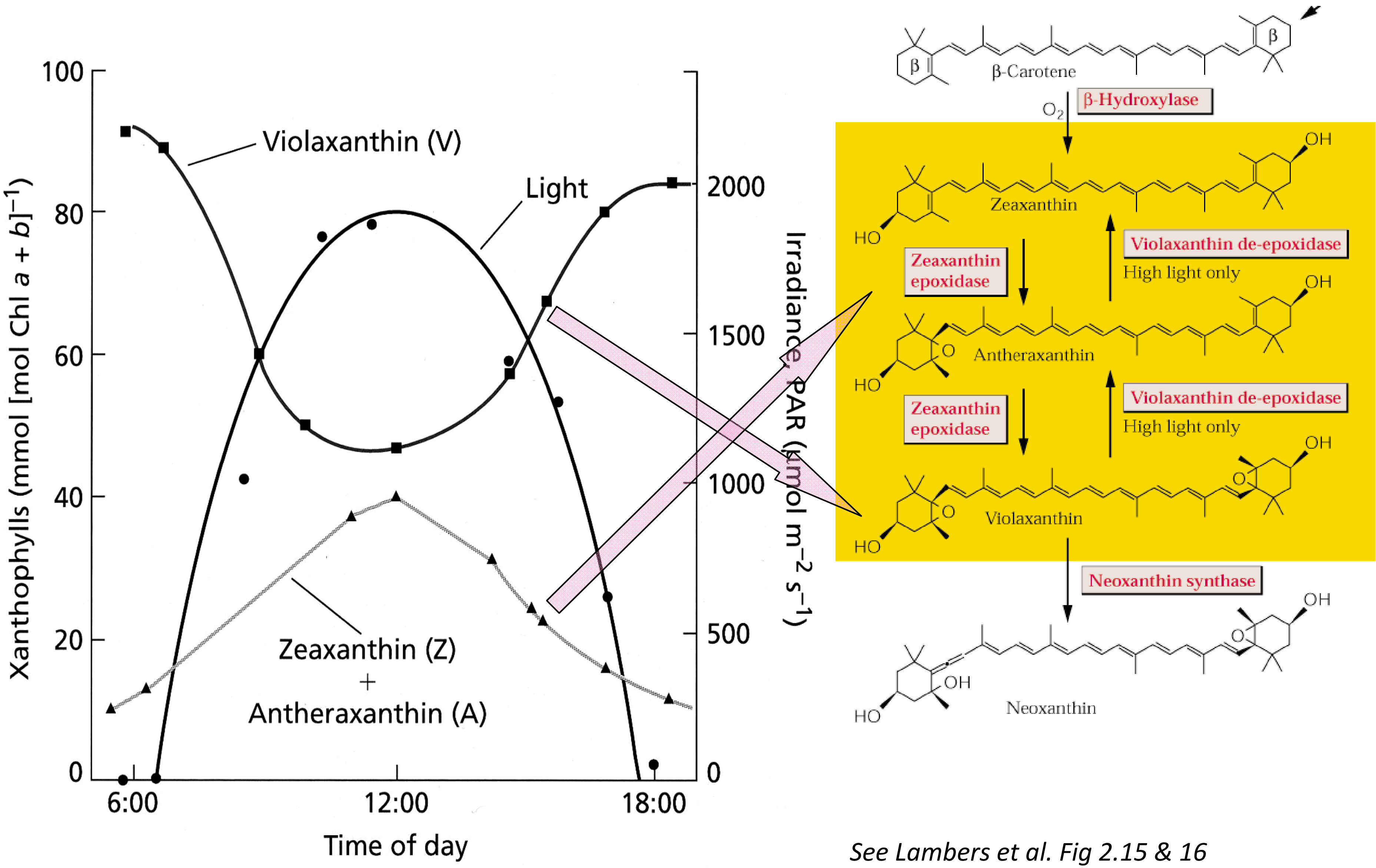
Protective Mechanisms Operate to Dissipate Absorbed Light

Wasteful but Essential for Survival

?

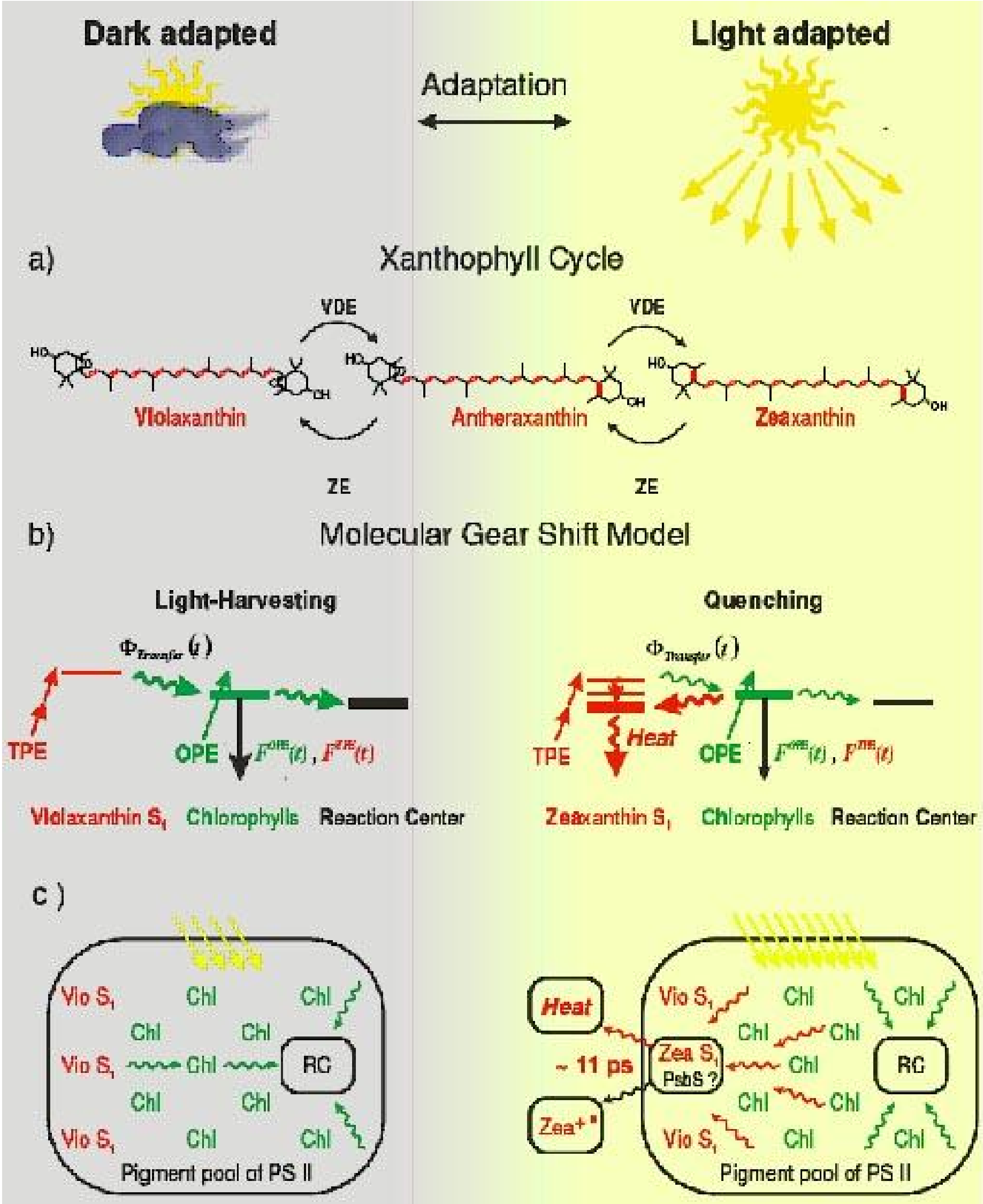


Xanthophyll Cycle Operates in Light Harvesting Complexes (LHCs) with Changing Irradiance Levels



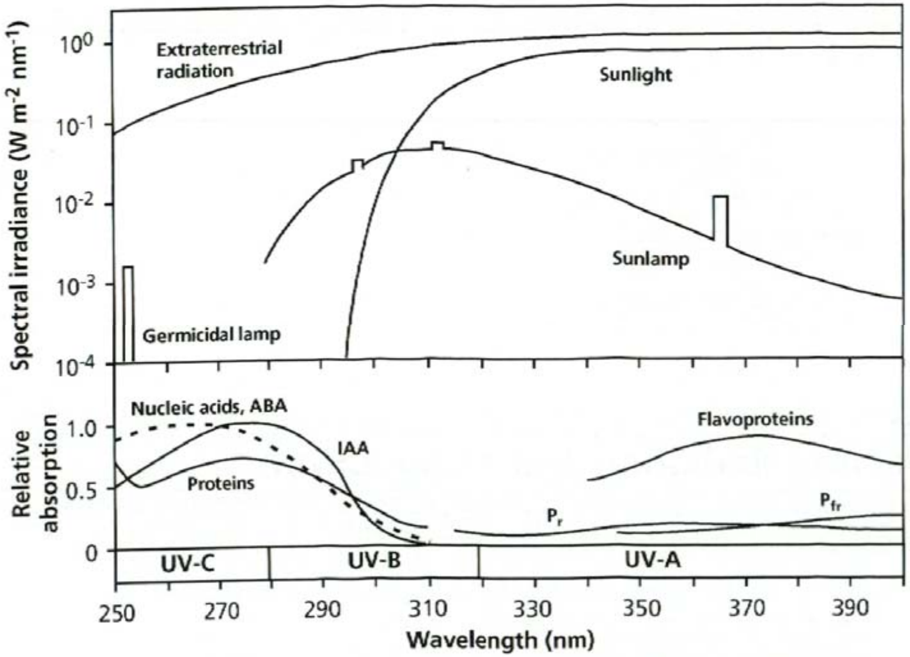
See Lambers et al. Fig 2.15 & 16

Zeaxanthin / Antheraxanthin 'Quench' Captured Energy by Conversion to Heat

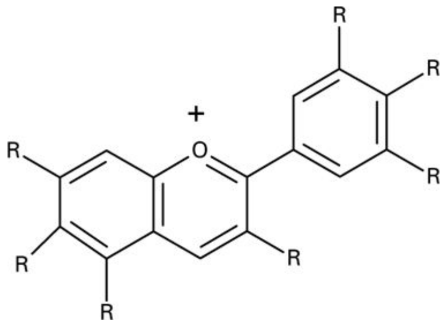


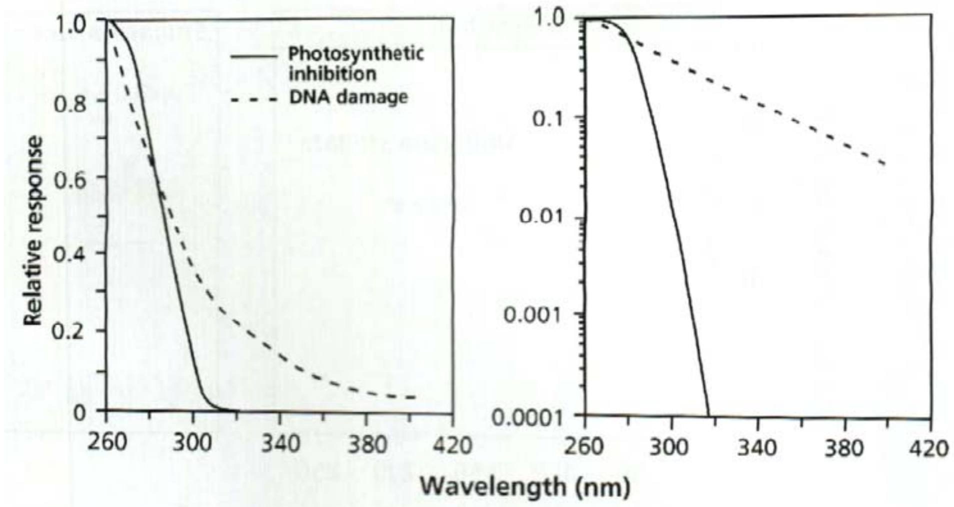
See Lambers et al. Fig 2.9C

UV Radiation



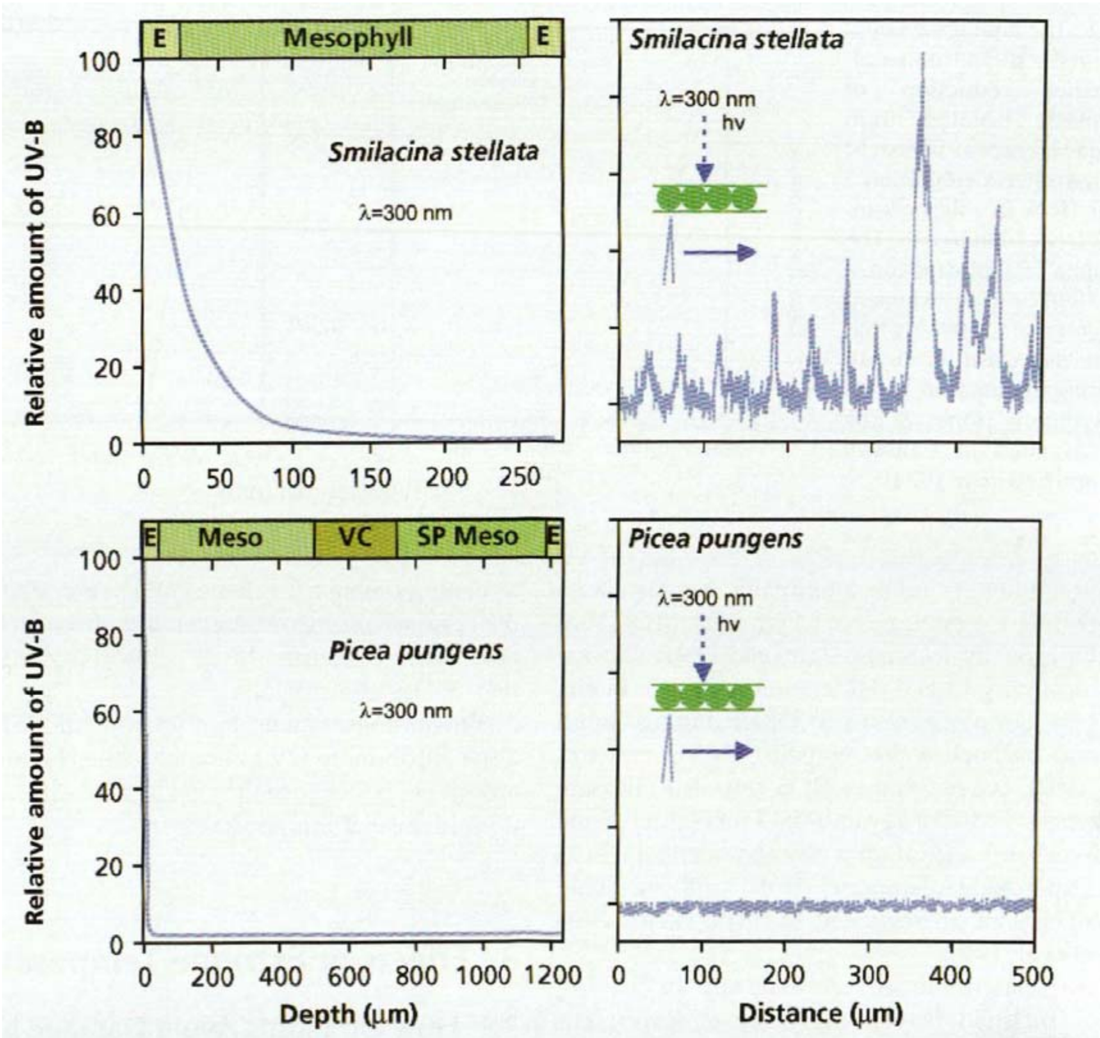
Protection by:
Flavonols
ROS scavangers





UV Penetration in Leaves

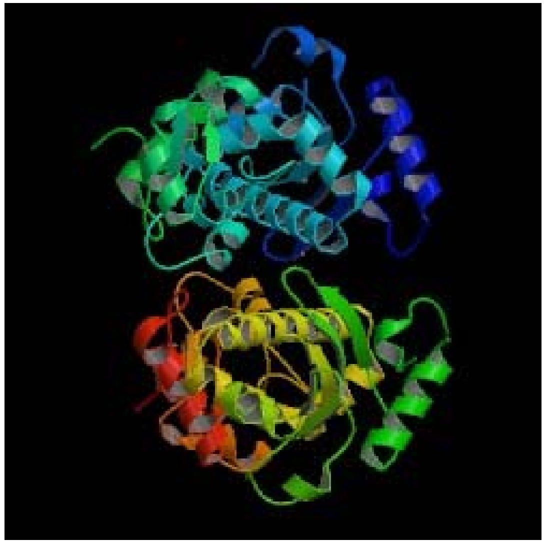
Conifer Leaves
- Better Protected than Angiosperm Leaves



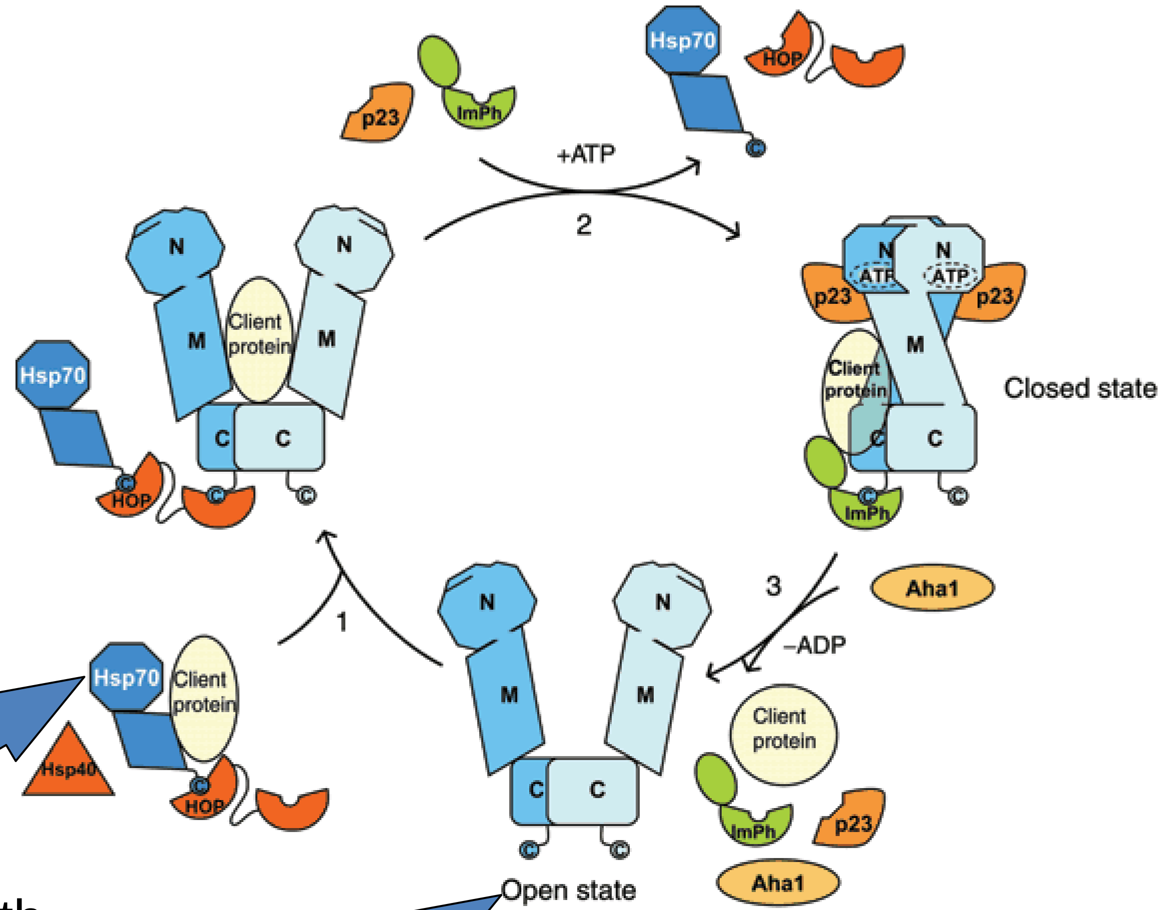
Extremes of Temperature

- In High Light & Low Temperature, Light Harvesting Complexex form $^3Chl^* \rightarrow {}^3O_2: \rightarrow$ ROS
    - Photoinhibition
    - Photooxidation
    - Xanophyll Cycle
    - Photorespiration
- Protection By:
    - Ascorbate (vitamin C)
    - Glutathione
    - a-tocopherol (vitamin E)
    - b-Carotene / carotenoids (vitamin A)
    - Superoxide dismutase (SOD; $^-O_2 \rightarrow H_2O_2$)
    - Catalase ($H_2O_2 \rightarrow H_2O/O_2$)

Heat Shock (& other Stresses) Result in the Synthesis of 'Heat Shock Proteins'



Hsp90 dimer



Hsp70 & Hsp40 load Hsp90 with denatured protein

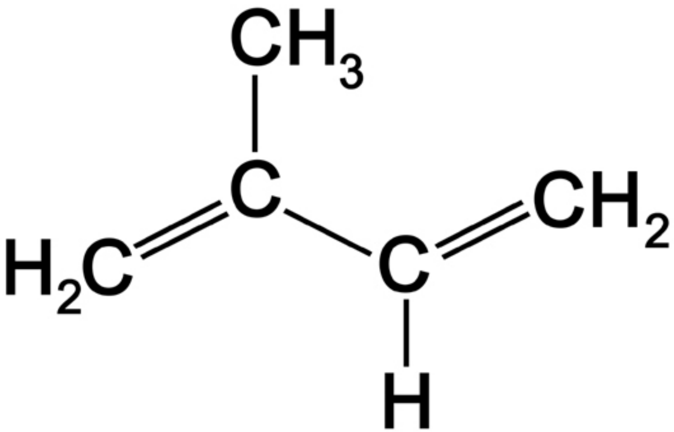
Hsp90 dimer is a protein clamp

Heat Shock Proteins

Approximate molecular weight (kDa)	Prokaryote Proteins	Eukaryote Proteins	Function
10 kDa	GroES	Hsp10	
20-30 kDa	GrpE	HspB group	Organelles and ER
40 kDa	DnaJ	Hsp 40	Cytoplasm, Chloroplast & Mitochondria
60 kDa	GroEL 60 kDa antigen	Hsp 60	Involved in protein folding after its post-translational import to the mitochondrion/chloroplast
70 kDa	DnaK	HspA group	Protein folding and unfolding in cytoplasm, provides thermotolerance to cell on exposure to heat stress. Also prevents protein folding during post-translational import into the mitochondrial/chloroplast
90 kDa	HtpG C62.5	HspC group Hsp90 Grp94	Maintenance of steroid receptors and transcription factors. Cytoplasm & ER
100 kDa	ClpB ClpA ClpX	Hsp104 Hsp110	Tolerance of extreme temperature. Cytoplasm

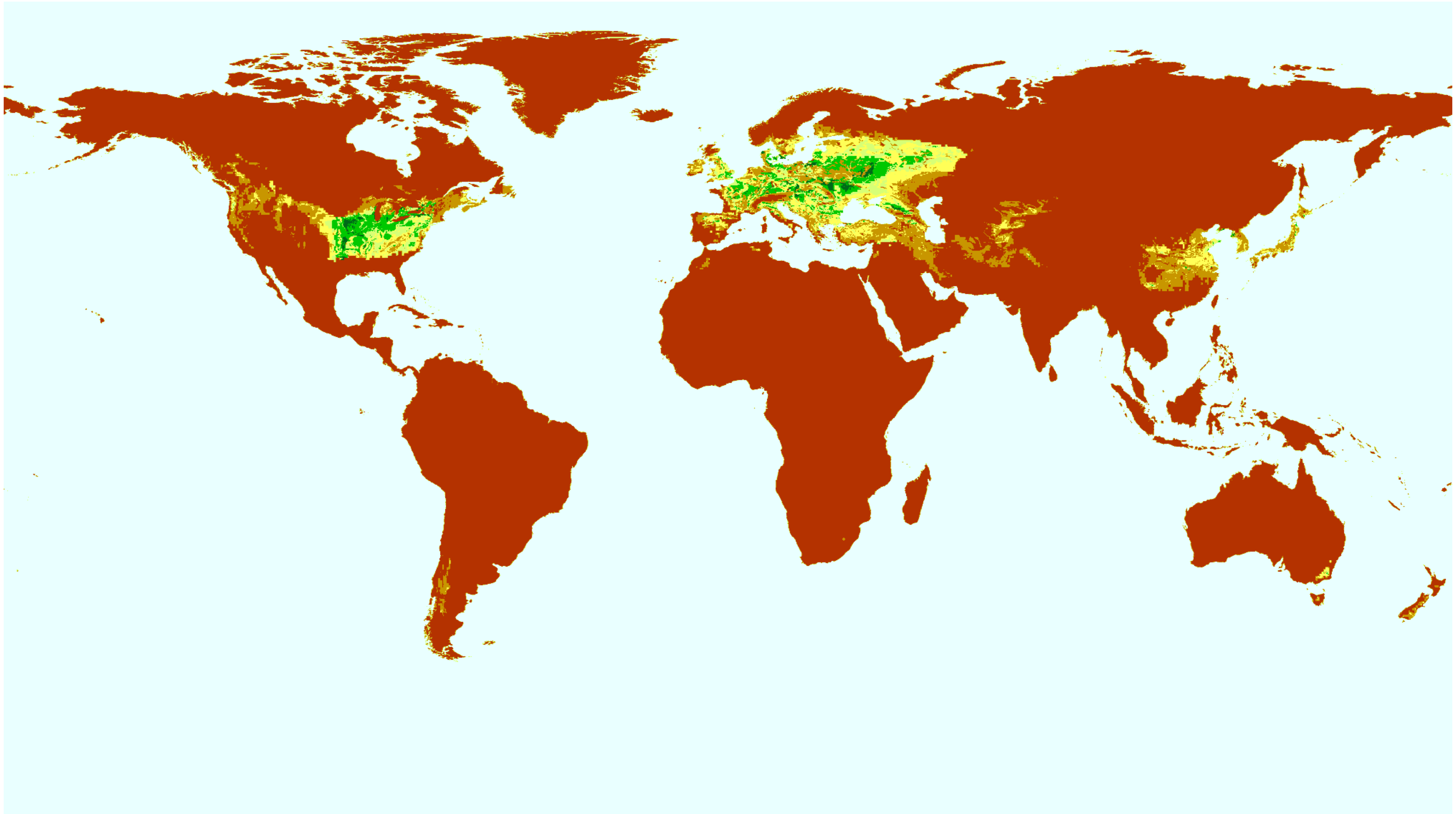
Isoprene Emissions

- 180-450 . 10^9 kg $year^{-1}$
- Typically 15%, Up to 50% Fixed Carbon
- Increases with T_{leaf}
- Response to High Temperature?



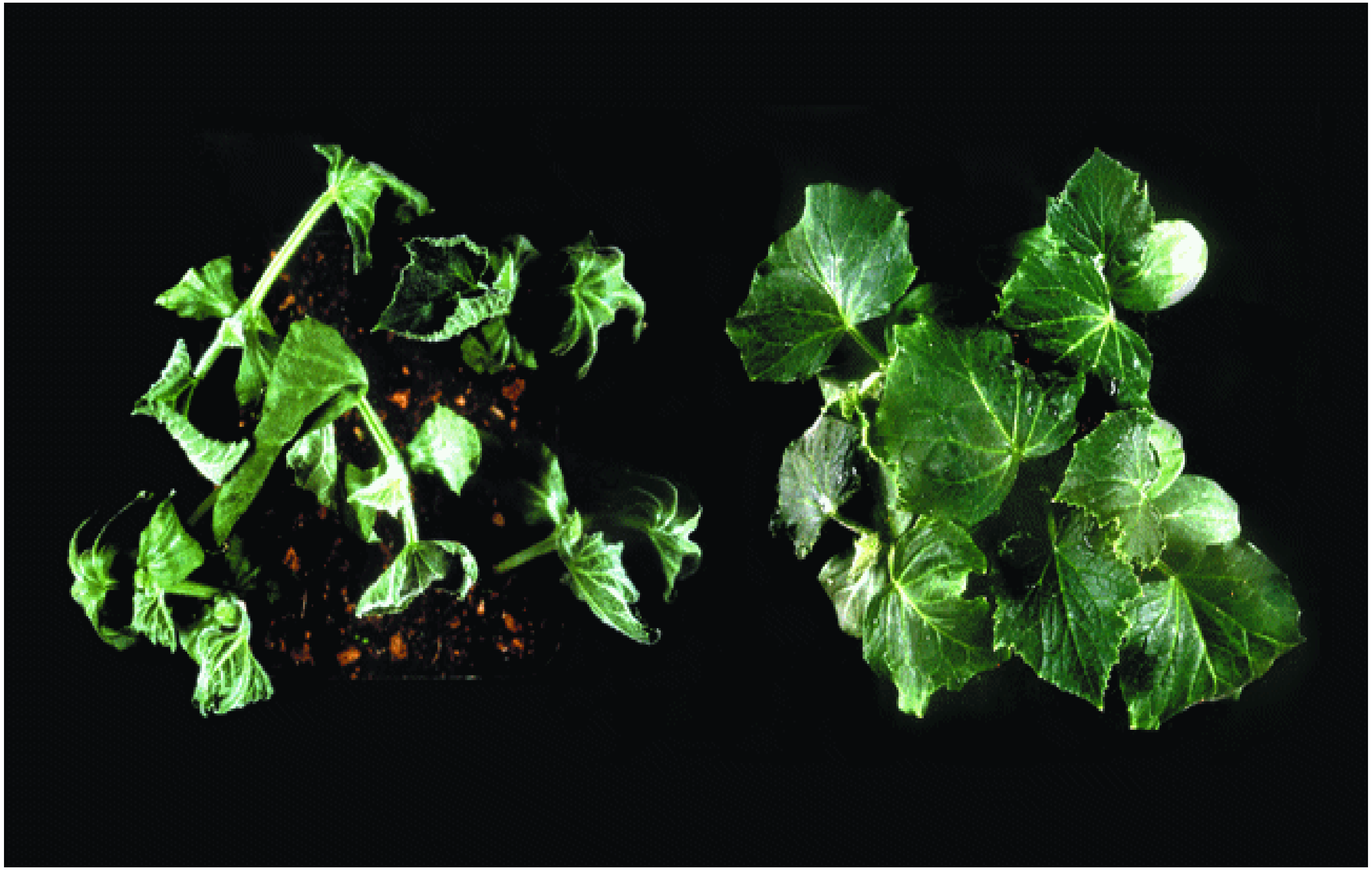
Isoprene (2-methyl-1,3-butadiene)

Wheat *Triticum aestivum*

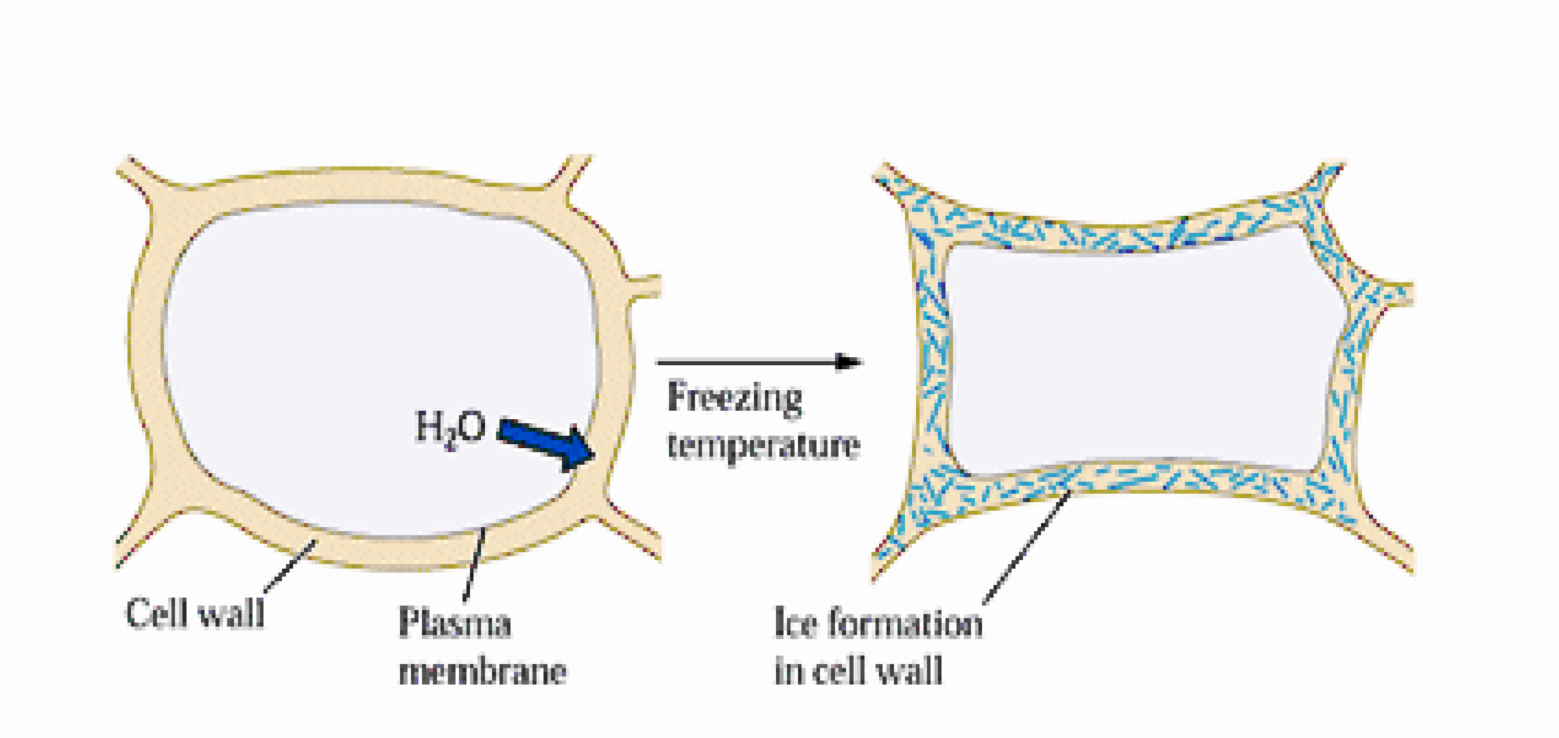


The range of wheat is determined by the ‘number of frost-free days’ and rainfall

Exposure to Chilling or Freezing Temperatures can Cause Damage to Plants



Freezing Temperatures Cause Desiccation

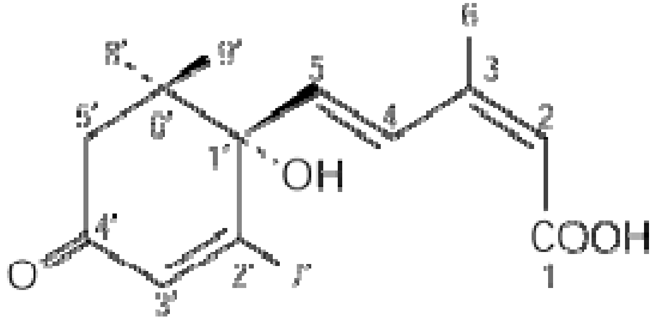


- During the freezing process, extracellular ice forms...
- ...water leaves the cell - about 90% by -10ºC - ...
- ...resulting in a loss of Y_p ...
- ...and eventually plasmolysis

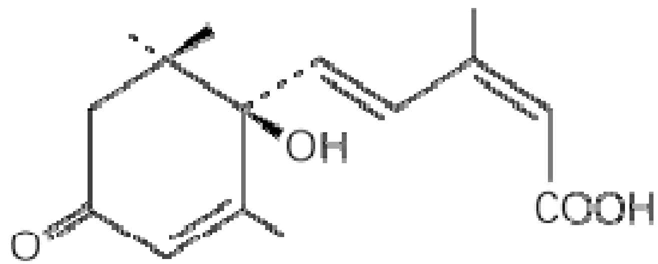
A Period of Cold Acclimation can Prevent Frost Damage

- Arabidopsis plants were grown at 23 C
- the pot on the right was then transferred to 4 C for 4 days
- both were then transferred to -5 C for 4 days..
- ..before being transferred back to 23 C

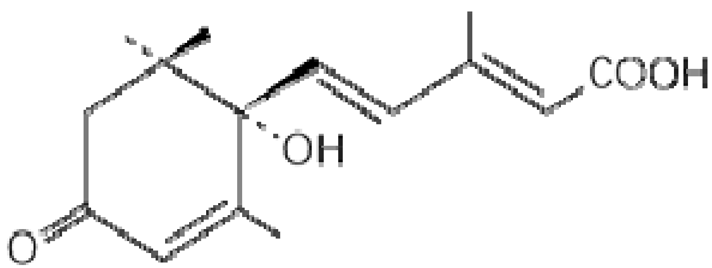
The Phytohormone ABA is Elevated During Cold Acclimation



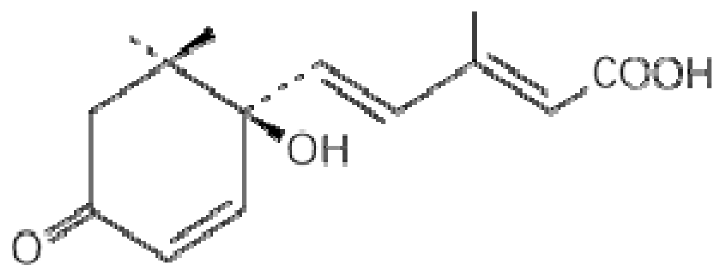
(*S*)-ABA



(*R*)-ABA

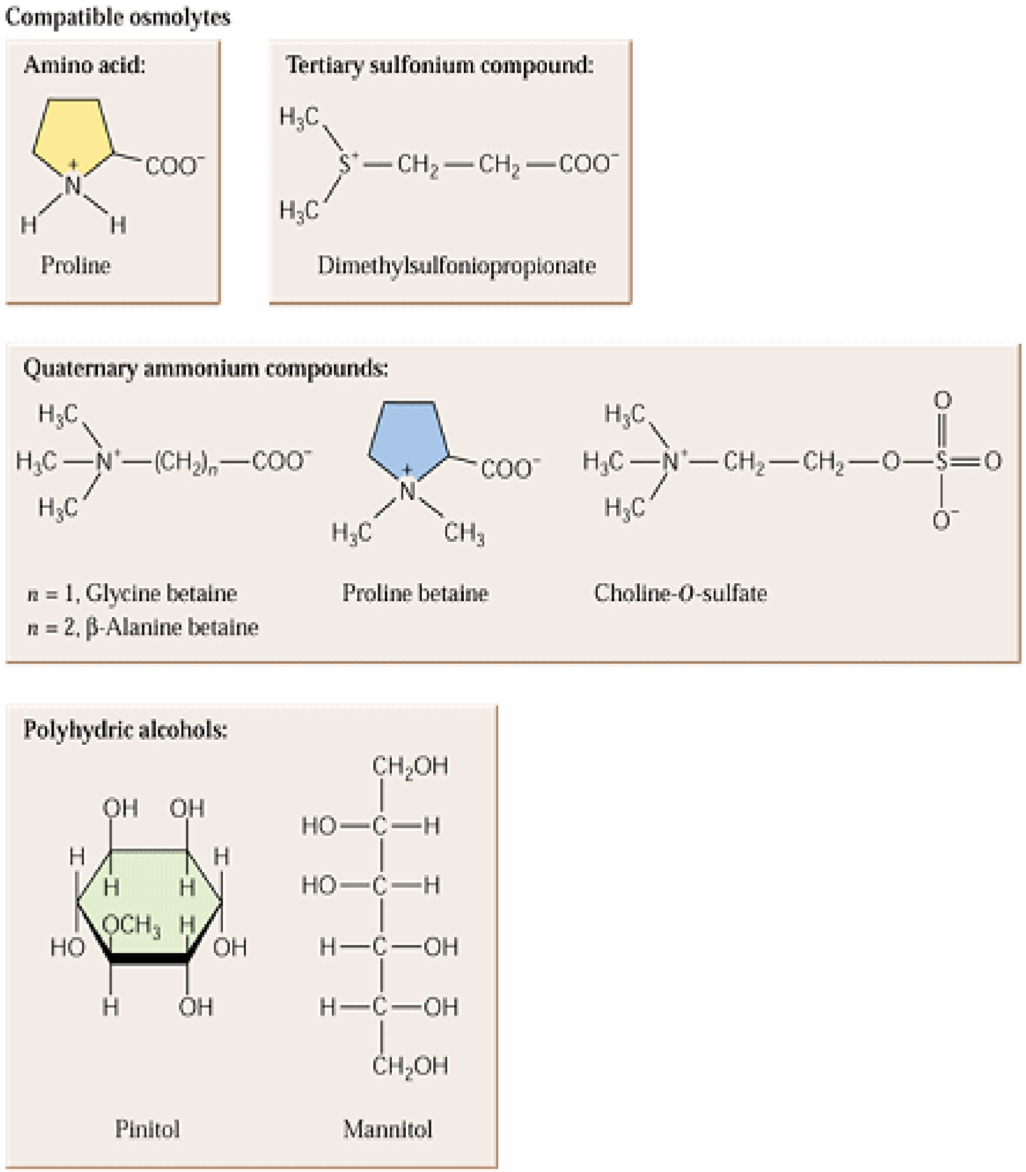


(*S*)-2-*trans*-ABA

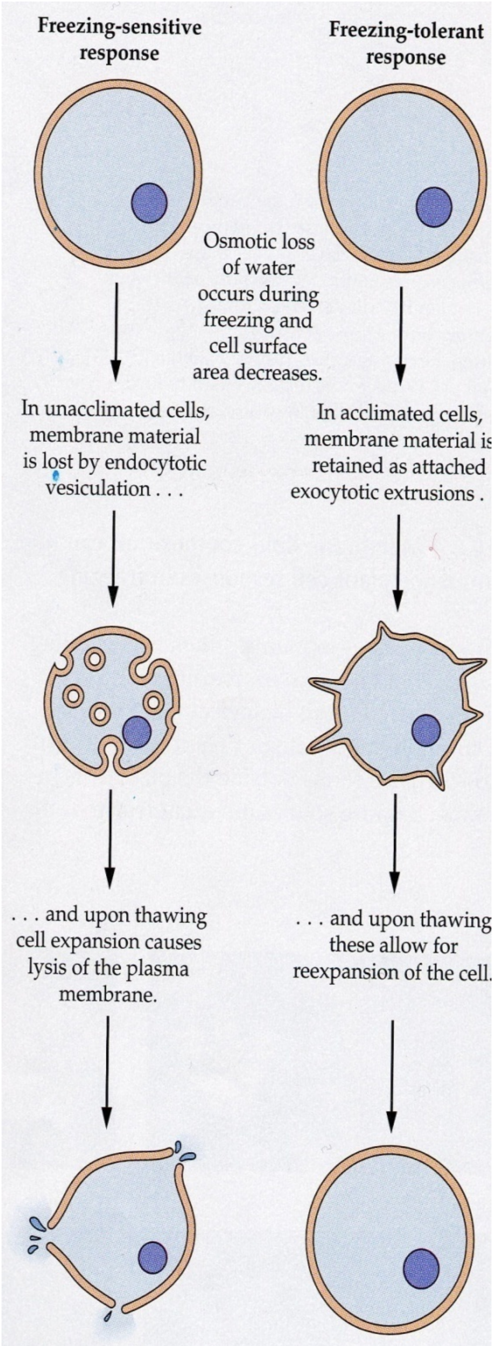


(*R*)-2-*trans*-ABA

Plants Synthesize Compatible Solutes in Response to Water Stress



- Compatible solutes include:
  - proline
  - Tertiary Sulfonium Compounds (TSCs)
  - Quaternary Ammonium Compounds (QACs)
  - Polyhydric alcohols



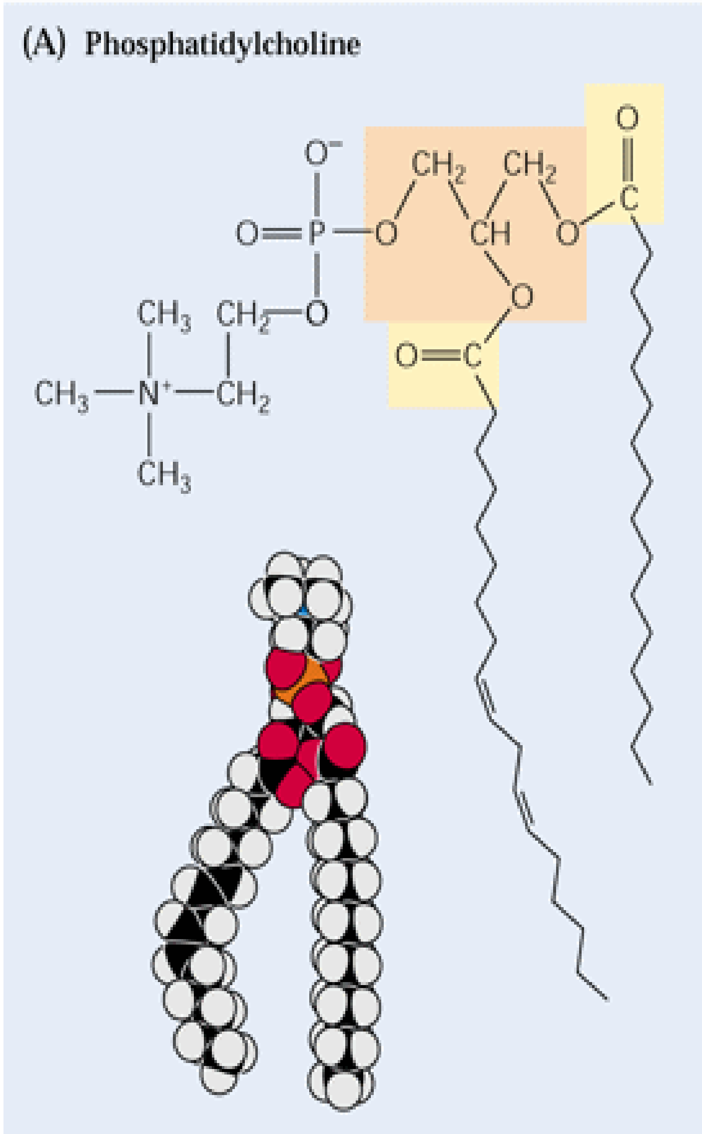
Cold Acclimated & Non-Acclimated Cells Freeze in a Different Way

- The plasma membrane of non-acclimated cells produce intracellular vesicles when they dehydrate...

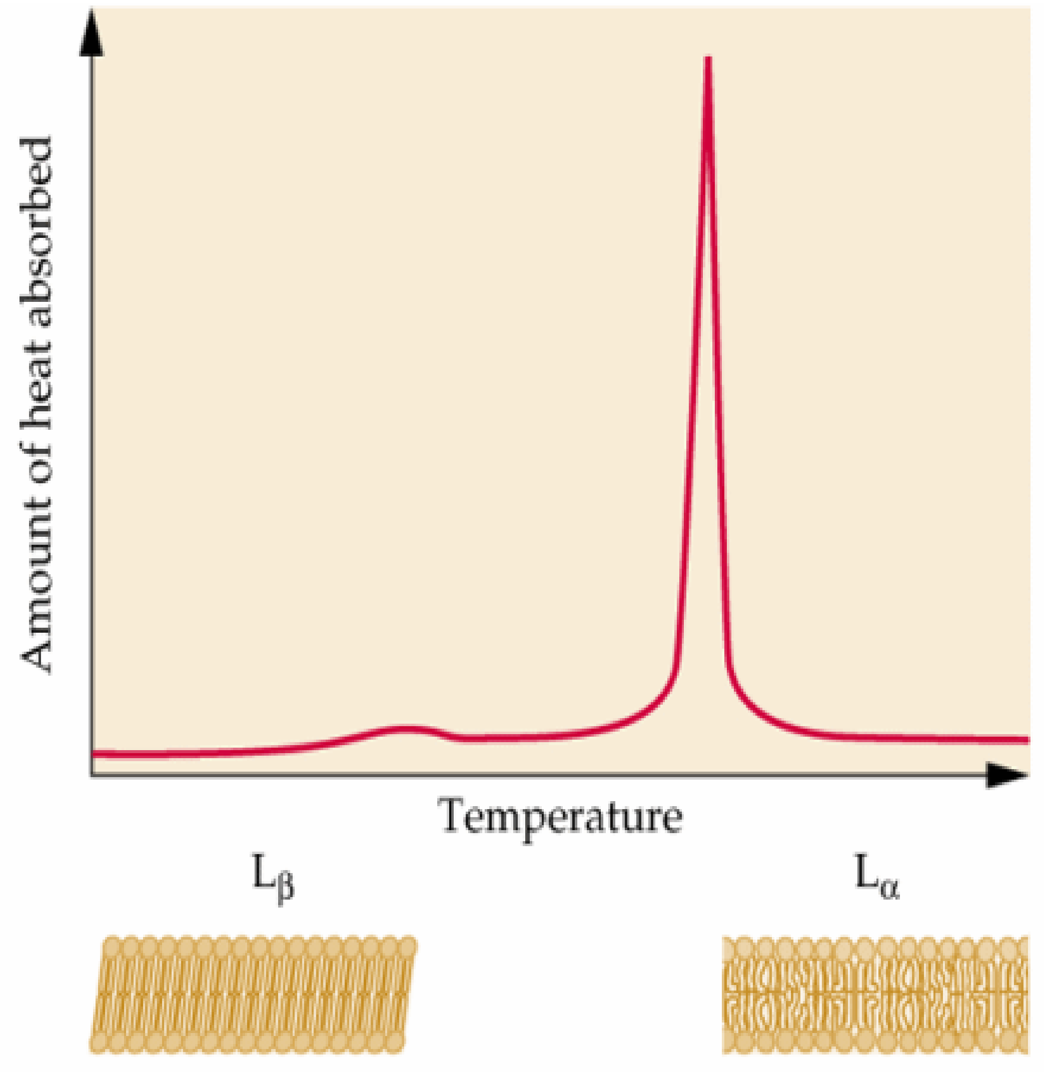
- The plasma membranes of Cold Acclimated Cells produce extracellular protrusions when they dehydrate...

Cold Acclimation Produces Major Changes in the Chemical Composition of Membrane Lipid - I

- ...membrane lipids become more unsaturated...
- ...which introduces kinks in the fatty acid chains...
- ...thereby reducing the attractive Van der Waals forces...
- ...and reducing the temperature of the liquid crystalline-to-gel phase transition



Cold Acclimation Produces Major Changes in the Chemical Composition of Membrane Lipid - II

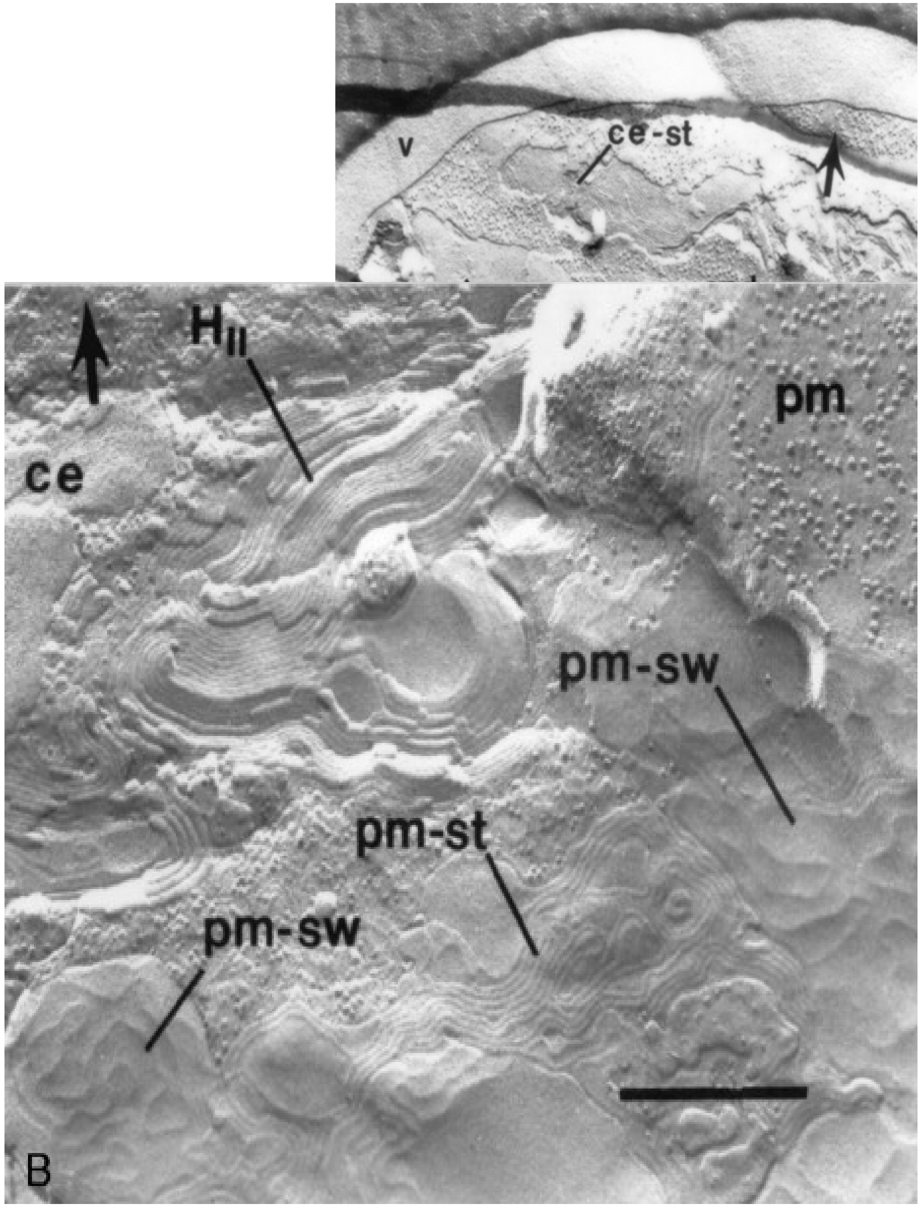


- membranes in the gel phase are not fluid and not functional
- L_a-to-Hex_{II} transitions are also important

Freezing Tolerance Genes

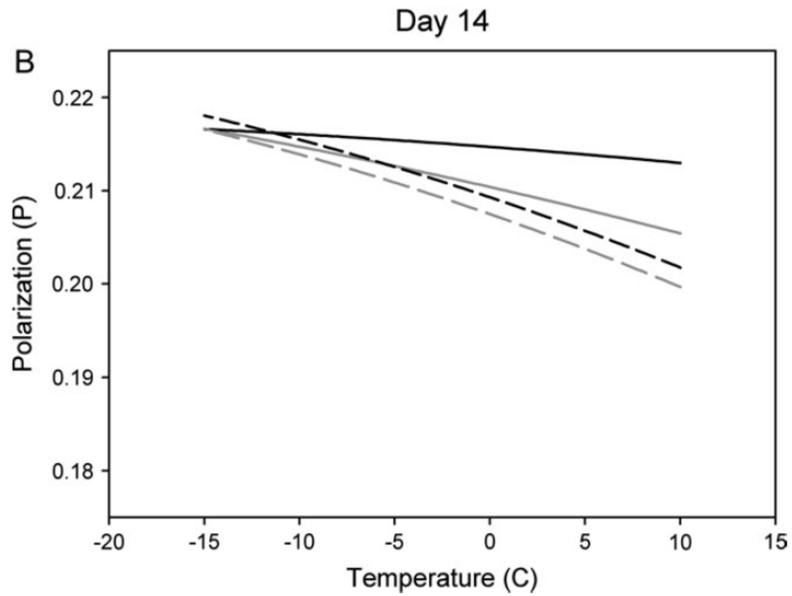
Steponkus *et al.* (1998) Proc Natl Acad Sci 95:14570-14575

- Hex_{II} structures in the plasma membrane. This shows up as 'string'. This lipid phase change may be more important than 'liquid-crystalline-to-gel' phase transitions.



Membrane Fluidity Changes?

- Lipid Desaturation Increases with Cold Stress as shown by the Double Bond Index (DBI).
- Polarization measures 'Fluidity'; value of 0 is 'Fluid', 1.0 'non-Fluid'; are these Small Observed Changes Significant?



Days after treatment	Treatment	Acyl lipid composition (mol %)					DBI
		16:0	18:0	18:1	18:2	18:3	
4	Control −ABA	36.42 (0.657)	13.70 (0.240)	3.28 (0.235)	24.50 (1.040)	22.10 (0.380)	1.18 (0.025)
4	Control +ABA	36.80 (0.347)	18.35 (0.519)	6.93 (0.228)	19.32 (0.392)	23.59 (0.650)	1.16 (0.037)
4	Low −ABA	31.49 (0.256)	10.20 (0.119)	3.10 (0.048)	32.36 (0.522)	22.83 (0.314)	1.36 (0.010)
4	Low +ABA	29.95 (0.725)	8.72 (0.059)	3.17 (0.024)	34.81 (0.655)	23.34 (0.089)	1.43 (0.030)
14	Control −ABA	33.04 (0.696)	12.76 (0.105)	3.29 (0.046)	27.34 (0.658)	23.57 (0.097)	1.29 (0.025)
14	Control +ABA	23.58 (0.673)	22.97 (0.495)	8.96 (0.295)	27.14 (0.985)	22.87 (0.432)	1.32 (0.105)
14	Low −ABA	30.56 (0.752)	6.36 (0.528)	2.59 (0.512)	30.48 (0.263)	30.00 (0.570)	1.54 (0.065)
14	Low +ABA	27.07 (0.398)	8.90 (0.044)	3.00 (0.066)	20.73 (0.465)	40.28 (0.219)	1.65 (0.017)