

Lecture 21-2:

Abiotic stresses

Heat stress

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Heat stress and heat shock

- Most tissues of higher plants are unable to survive extended exposures to temperatures above 45°C.

- Non-growing cells or dehydrated tissues (seed, pollen) can survive higher temperatures than hydrated tissue.

- Dry seeds can endure 120°C.

- Pollen of some species can endure 70°C.

- Periodic brief exposures to sub-lethal heat stresses induces tolerance to otherwise lethal temperatures (**induced thermotolerance**).

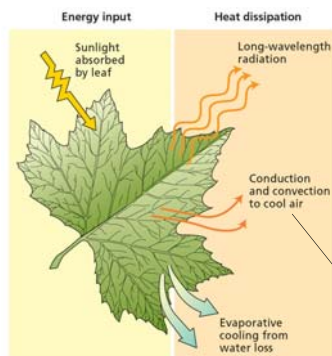
Heat-killing temperatures for plants

Plant	Heat-killing temperature (C°)	Time of exposure
<i>Nicotiana rustica</i> (wild tobacco)	49-51	10 min
<i>Cucurbita pepo</i> (squash)	49-51	10 min
<i>Zea mays</i> (corn)	49-51	10 min
<i>Brassica napus</i> (rape)	49-51	10 min
<i>Citrus aurantium</i> (sour orange)	50.5	15-30 min
<i>Opuntia</i> (cactus)	>65	—
<i>Sempervivum arachnoideum</i> (succulent)	57-61	—
Potato leaves	42.5	1 hour
Pine and spruce seedlings	54-55	5 min
<i>Medicago</i> seeds (alfalfa)	120	30 min
Grape (ripe fruit)	63	—
Tomato fruit	45	—
Red pine pollen	70	1 hour
Various mosses	—	—
Hydrated	42-51	—
Dehydrated	85-110	—

Source: After Table 11.2 in Levitt 1980.

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High leaf temperature and water deficit lead to heat stress



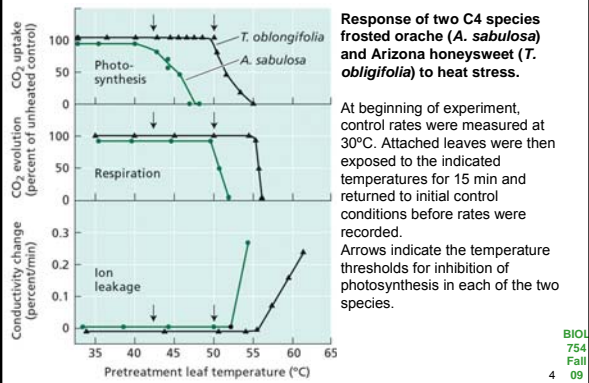
Many CAM and succulent higher plants (*Opuntia*, *Sempervivum*) are adapted to high temperatures and can tolerate tissue temperatures of 60-65°C under intense irradiation in the summer.

CAM keep stomata closed during day → cannot cool by transpiration; dissipate heat by re-emission of long-wave (infrared) radiation and loss of heat by conduction and convection.

Air circulation around the leaf removes heat from the surface if temperature of leaf is higher than that of air.

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At high temperatures, photosynthesis is inhibited before respiration



Plants adapted to cold temperatures acclimate poorly to high temperatures



Frosted orache (*Atriplex sabulosa*)
Chenopodiaceae
Native to the cool climate of Northern CA



Arizona honeysweet (*Tidestromia oblongifolia*) Amaranthaceae
Native to very hot climate of Death Valley, CA

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High temperature reduces membrane stability

Excessive fluidity of membrane lipids at high temperatures is correlated with loss of physiological function.

In oleander (*Nerium oleander*), acclimation to high temperatures is associated with a greater degree of saturation of fatty acids in membrane lipids, making the membranes less fluid.

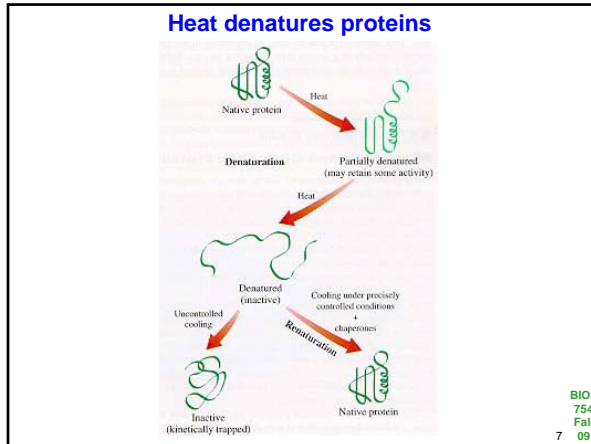
High temperatures modify composition and structure of membranes and can cause leakage of ions.

Photosynthesis is particularly sensitive to high temperature; enzymes denature:

- RUBISCO
 - NADP:glyceraldehyde-3-phosphate dehydrogenase
 - PEP carboxylase
- These enzymes are less stable at high temperature in *A. sabulosa* than in *T. oblongifolia*.

Temperature at which these enzymes denature is higher than temperature at which photosynthesis declines → heat injury is more directly related to changes in membrane properties and to uncoupling of energy transfer than to denaturation of proteins.

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At higher temperatures, plants produce Heat Shock Proteins (HSP)

- HSPs are produced in response to sudden, 5-10°C rises in temperature.
- HSP help cells to withstand heat stress by acting as molecular chaperones to prevent misfolding of proteins.
- Heat stress causes many enzymes or structural components to become unfolded or misfolded, thereby leading to loss of proper enzyme structure and activity.
- Misfolded proteins aggregate and precipitate within the cell.
- First discovered in *Drosophila*.
- mRNA of HSPs up-regulated within 3-5 min after heat shock.
- Some HSPs are found in normal, unstressed cells and do not increase in response to thermal stress.
- Plants and most other organisms make HSPs of different sizes.

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At higher temperatures, plants produce Heat Shock Proteins (HSP)

The five classes of heat shock proteins found in plants

HSP class	Size (kDa)	Examples (<i>Arabidopsis</i> / prokaryotic)	Cellular location
HSP100	100-114	AtHSP101 / ClpB, ClpA/C	Cytosol, mitochondria, chloroplasts
HSP90	80-94	AtHSP90 / HtpG	Cytosol, endoplasmic reticulum
HSP70	69-71	AtHSP70 / DnaK	Cytosol/nucleus, mitochondria, chloroplasts
HSP60	57-60	AtTCP-1 / GroEL, GroES	Mitochondria, chloroplasts
smHSP	15-30	Various AtHSP22, AtHSP20, AtHSP18.2, AtHSP17.6 / IBPA/B	Cytosol, mitochondria, chloroplasts, endoplasmic reticulum

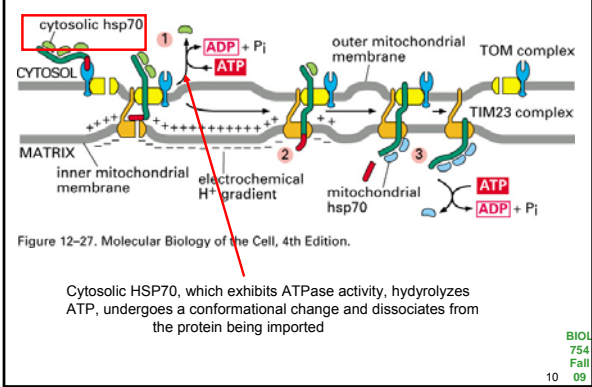
Source: After Boston et al. 1996.

HSP60, HSP70, HSP90, HSP100 act as molecular chaperones, involving ATP-dependent stabilization and folding of proteins and the assembly of oligomeric proteins.

Some HSP assist in polypeptide transport across membranes into cellular compartments.

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Some HSP assist in polypeptide transport across membranes



A transcription factor mediates HSP accumulation in response to heat shock

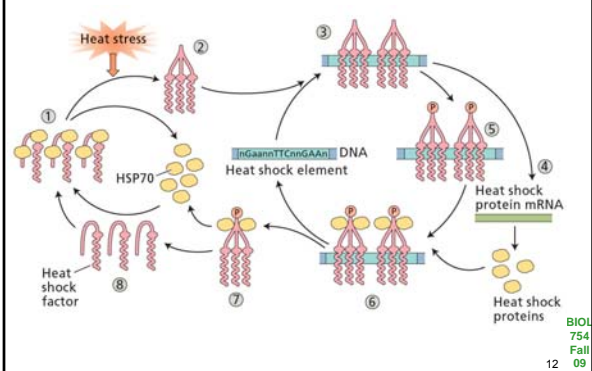
All cells contain chaperones that are constitutively expressed and function like HSPs → heat shock cognate proteins.

When subjected to heat stress, HSPs synthesis increases, while translation of other proteins decreases or ceases.

This heat shock response is mediated by a specific **heat shock factor** (HSF), encoding a transcription factor.

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The heat shock factor (HSF) cycle activates the synthesis of heat shock protein mRNAs



Regulation of GABA accumulation during heat stress

