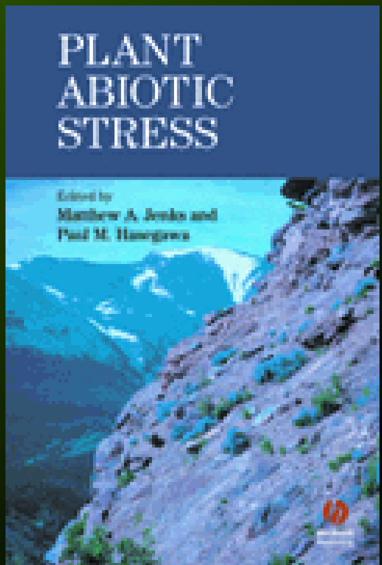
8) Plant responses to abiotic stress

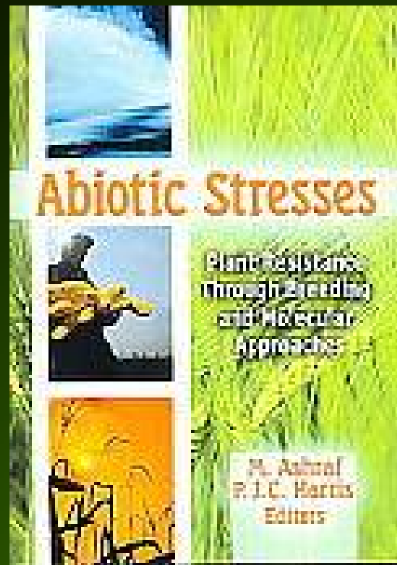
e) Thermal stress and thermal shock

f) Oxygen deficit



Jenks M *et al.* (2005) Plant Abiotic Stress. Blackwell Publishing

Ashraf M *et al.* (2005) Abiotic Stresses. The Haworth Press Inc.



e) Thermal stress and thermal shock

Tissues differ in the ability to tolerate high temperatures:

Actively growing and hydrated tissues of higher plants: to 45°C

Pollen grains: to 75°C

Dry seeds: to 120°C

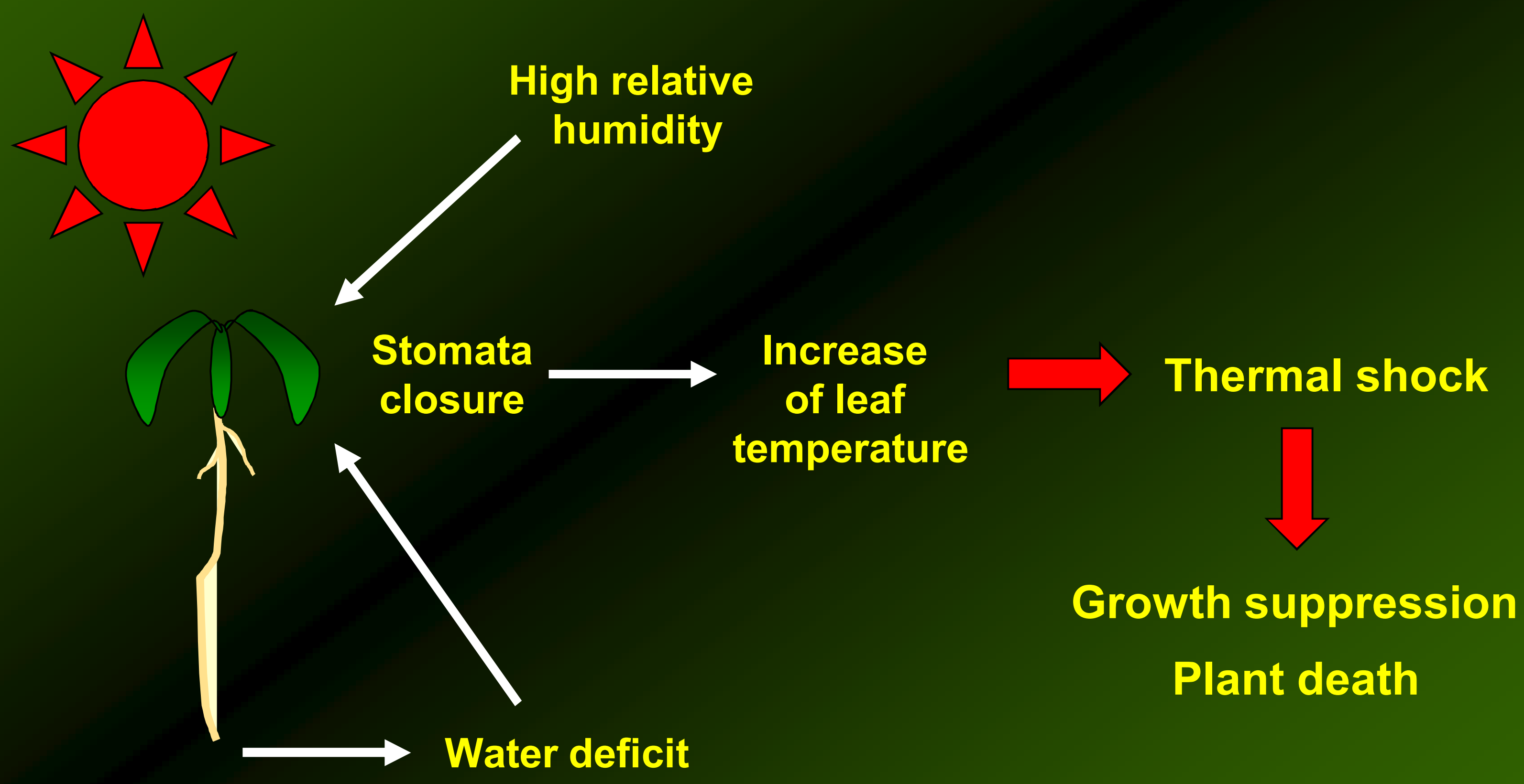
Thermotolerance – tolerance to higher temperatures induced by repetitive exposure of plant to sub-lethal temperatures

TABLE 25.3
Heat-killing temperatures for plants

Plant	Heat-killing temperature (C°)	Time of exposure
Nicotiana rustica (wild tobacco)	49–51	10 min
Cucurbita pepo (squash)	49–51	10 min
Zea mays (corn)	49–51	10 min
Brassica napus (rape)	49–51	10 min
Citrus aurantium (sour orange)	50.5	15–30 min
Opuntia (cactus)	>65	—
Sempervivum arachnoideum (succulent)	57–61	—
Potato leaves	42.5	1 hour
Pine and spruce seedlings	54–55	5 min
Medicago 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.

Thermal shock – high temperature of leaf and water deficit

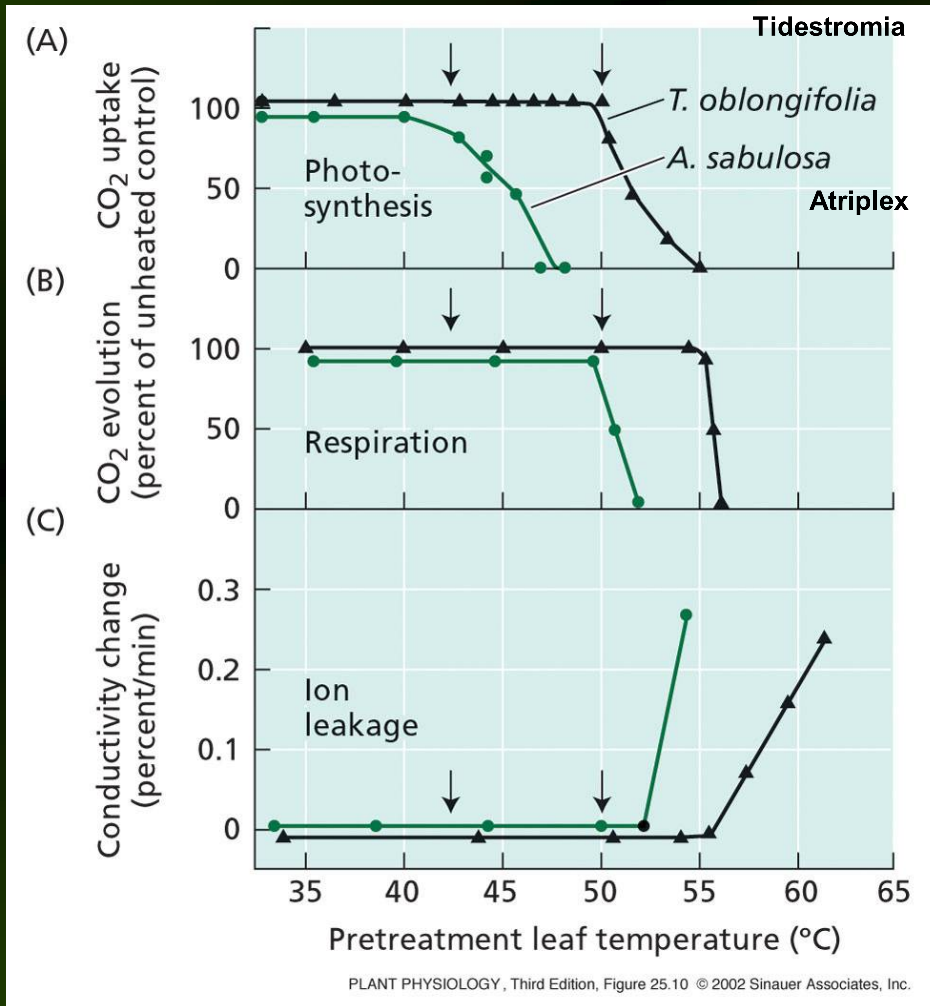


PMP

Photosynthesis and respiration are inhibited at high temperatures

Photosynthesis drops earlier than respiration

Photosynthesis – CO_2 fixation
Respiration – CO_2 release



Thermal compensation point:

Temperature at which the amount of CO_2 fixed by photosynthesis is equal to the amount of CO_2 released by respiration

Temperature > compensation point

↓

Drop of C in plant

↓

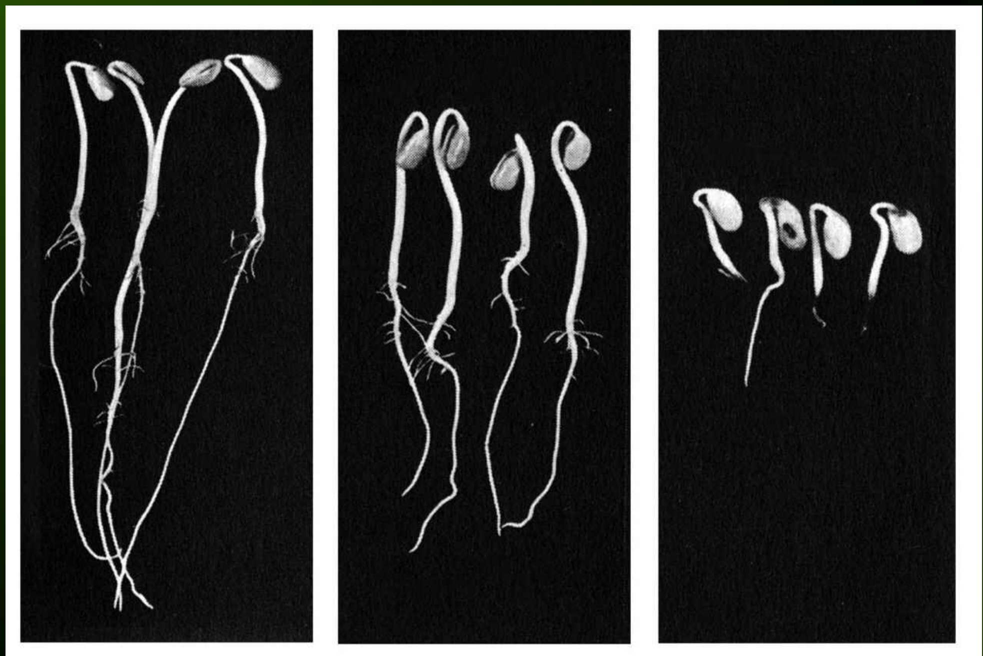
C for respiration taken from reserves

↓

Loss of fruit sweetness

Acclimatization to thermal stress → Synthesis of new proteins

Exposure to high but not lethal temperatures for several hours before thermal stress → Ability to survive lethal temperatures



28°C | 40°C => 45°C | 28°C => 45°C

Acclimatization of soy (*Glycine max*)

PMP

Atriplex sabulosa

Tidestromia oblongifolia

16°C : *Atriplex* ~ 75 % of normal growth
Tidestromia ~ bad growth

45°C : *Atriplex* ~ growth stopped
Tidestromia ~ maximal growth

Plants adapted to low temperatures acclimatize to higher temperatures with difficulties

Thermal stress decreases membrane stability

High membrane fluidity correlates with loss of physiological functions.

High temperature

↓

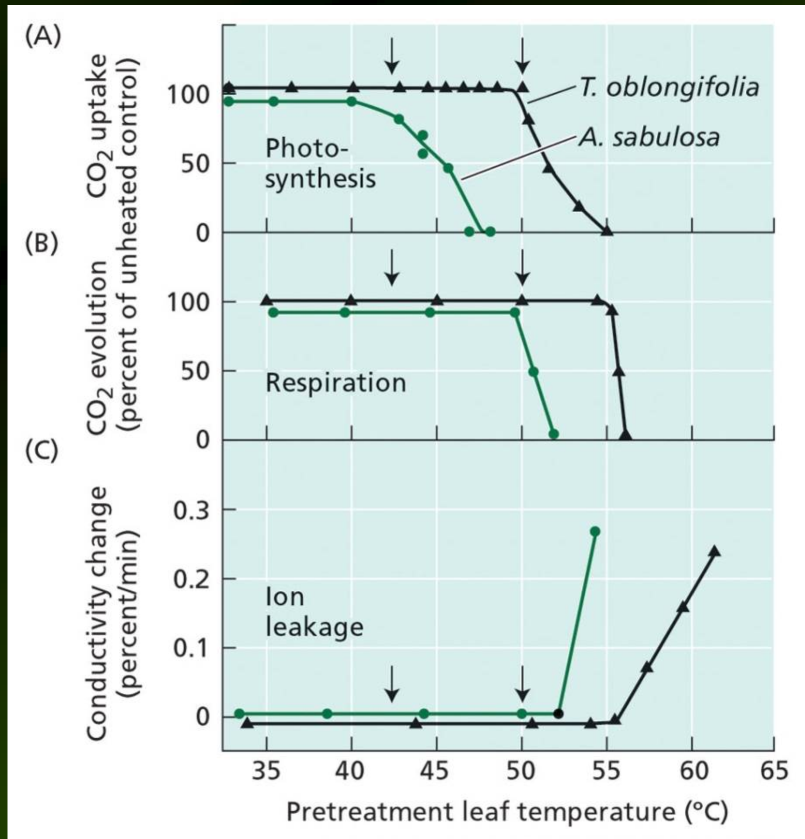
Lowering strength of hydrogen bond and electrostatic interaction between polar proteins

↓

Modification of membrane composition

↓

Ion leakage out of cell



PLANT PHYSIOLOGY, Third Edition, Figure 25.10 © 2002 Sinauer Associates, Inc.

Disruption of membrane stability

↓

Disruption of activity of electron carriers and enzymes

↓

Inhibition of photosynthesis and respiration

Photosynthesis – especially sensitive to higher temperatures

Temperature of denaturation of enzymes >> Temperature of inhibition of photosynthesis

In early phases of photosynthesis is caused by membrane destabilization, but not protein denaturation

In natural conditions plants protect themselves against excessive sunlight:

- Trichome formation
- Creation of waxy layer
- Leaf scrolling
- Growth of vertical leaves
- Growth of small leaves

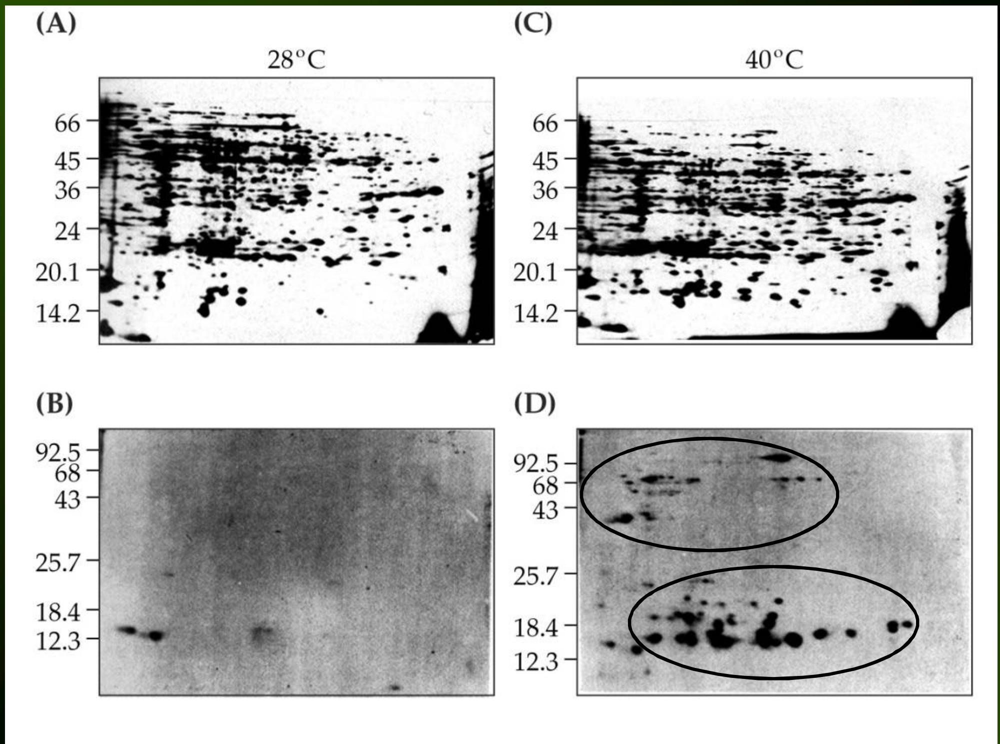
Leaf dimorphism: *Encelia farinosa*

Summer

Winter

Heat – Shock Proteins (HSP)

Increasing of temperature about 5 – 10°C → Increased production of normal proteins + Production of HSP → Function of chaperone



Production of HSP in soy on 2D gel

Incubation of plants in the presence of ^{3}H-leucinu at 28 and 40°C

↓ 3 hod

Protein extraction

↓

2D gel

Chaperone – protein that helps other proteins against unfavorable folding, which results in formation of inactive proteins

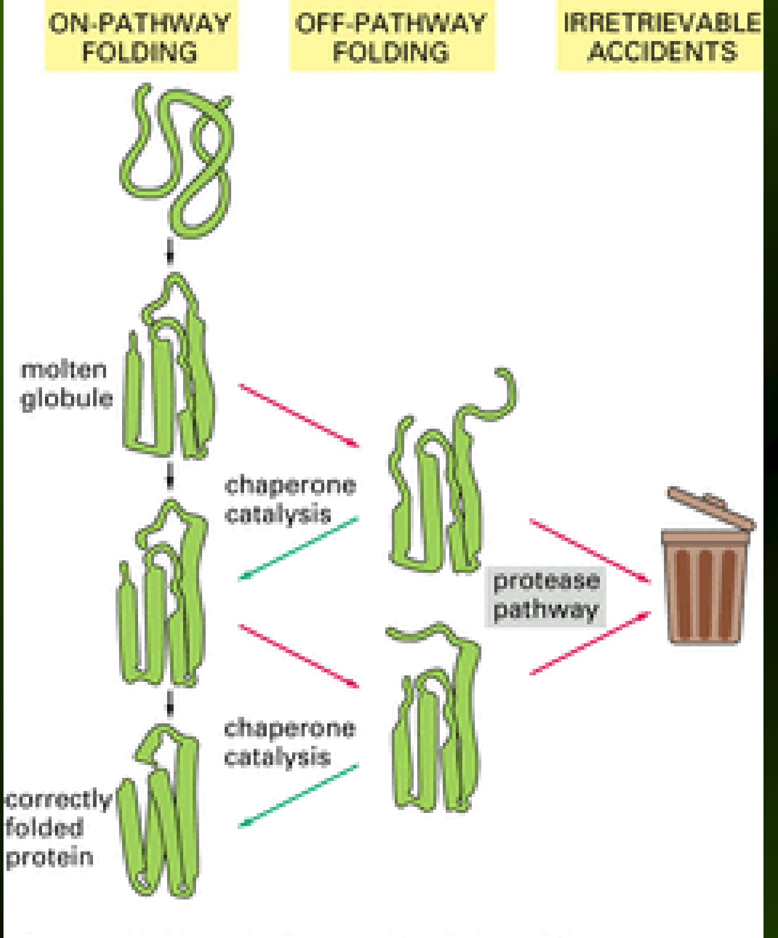


Figure 6-82. Molecular Biology of the Cell, 4th Edition.

Newly synthesized protein is immediately folded into „glowing globule“. Following folding is slow and goes by various ways. Increase of temperature alters protein folding. Chaperones repair wrong protein folding.

↓

Normal function of proteins

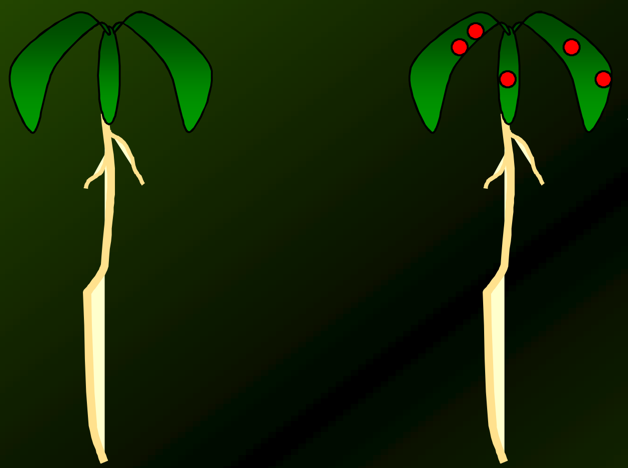
HSP – discovered in *Drosophila*; identified in other organisms, including human and plants

Complementation studies of mutants: Yeast mutant with deletion in HSP104 gene => loss of thermotolerance

Complementation by functional *Arabidopsis* gene HSP100

Restoration of thermotolerance

25°C : → 40°C :



Synthesis of HSP (30 – 50 types)
(new mRNA detected after 3-5 min)

Degradation of existing proteins

HSP form at gradual increasing of temperature – in nature

HSP were found also in non-stressed plants

Some essential proteins are homologous to HSP

Types of HSP: 15 – 104 kDa

TABLE 25.4
The five classes of heat shock proteins found in plants

HSP class	Size (kDa)	Examples (Arabidopsis / 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.

HSP 60, 70, 90, 100 – function as chaperones, ATP-dependent stabilization and folding of protein molecules

HSP 90 – associated with hormonal receptors in animal cells

Higher plants: smHSP, 15 – 30 kDa, 5 – 6 types; cytosol, chloroplast, ER, mitochondrion – function is not known

Some HSP are induced by other stresses or factors:

- Water deficit
- Hormone ABA
- Low temperature
- Salinity

} Cells gain cross-protection

Example: Tomato fruits exposed to $30^{o}C$ for 48 hrs accumulates HSP
Gain tolerance to cold stress.

HSP play essential role in acclimatization to thermal shock.

Evidences:

- Induction of plant tolerance to thermal stress correlates with induction of HSP accumulation.
- Activation HSF induces constitutive synthesis of HSP and increases thermotolerance.
- Transgenic plants *Arabidopsis* containing antisence DNA (reduces HSP70 synthesis) show reduced tolerance to thermal shock.

↓

Loss of capacity to synthesize HSP70 results in loss of thermotolerance

Thermal stress affects functioning of enzymes, which are parts of metabolic pathways => accumulation of metabolites, reduction of other metabolites

Thermal stress influences metabolic responses, which consumes or produces protons => influence on H^+-ATPase

Thermal stress reduces activity of H^+-ATPase, which pumps H^+ out of cytosol into apoplast or into vacuoles

↓

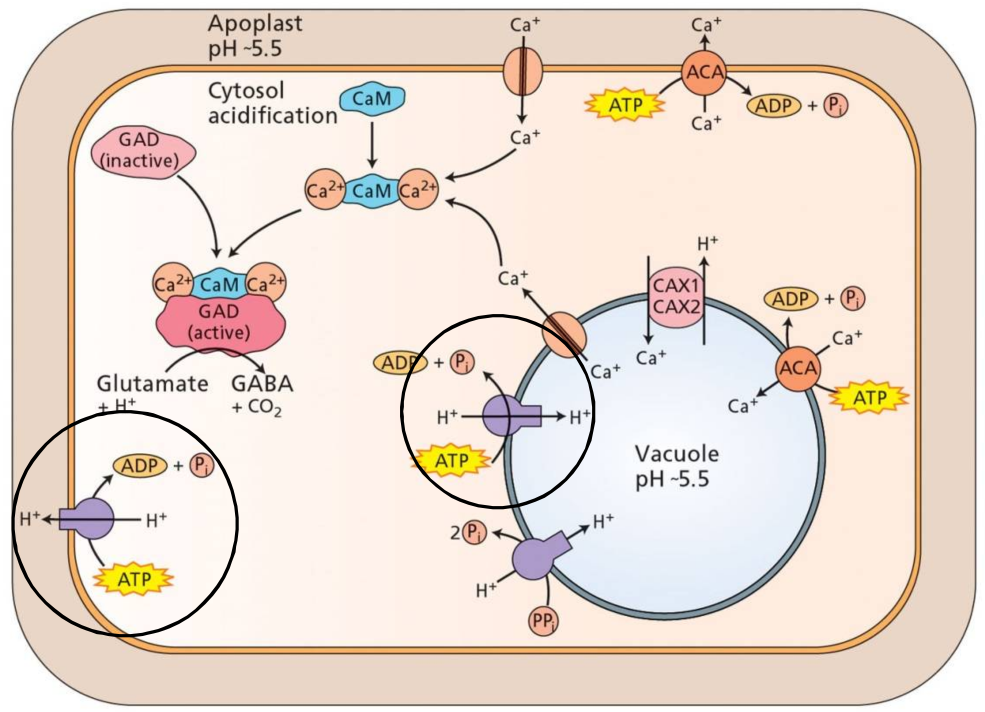
Cytosol acidification

↓

Other metabolic changes

↓

Mechanisms of acclimatization



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Metabolic acclimatization to thermal stress – accumulation of GABA (γ-amino butyric acid)

GABA – „useless amino acid “; it is synthesized from L-glutamate using enzyme glutamate dekarboxylase (GAD).

GAD – the activity is modulated by calmodulin (Ca^{2+} receptor)

Thermal stress

↓

Ca^{2+} in cytosol ↑

↓

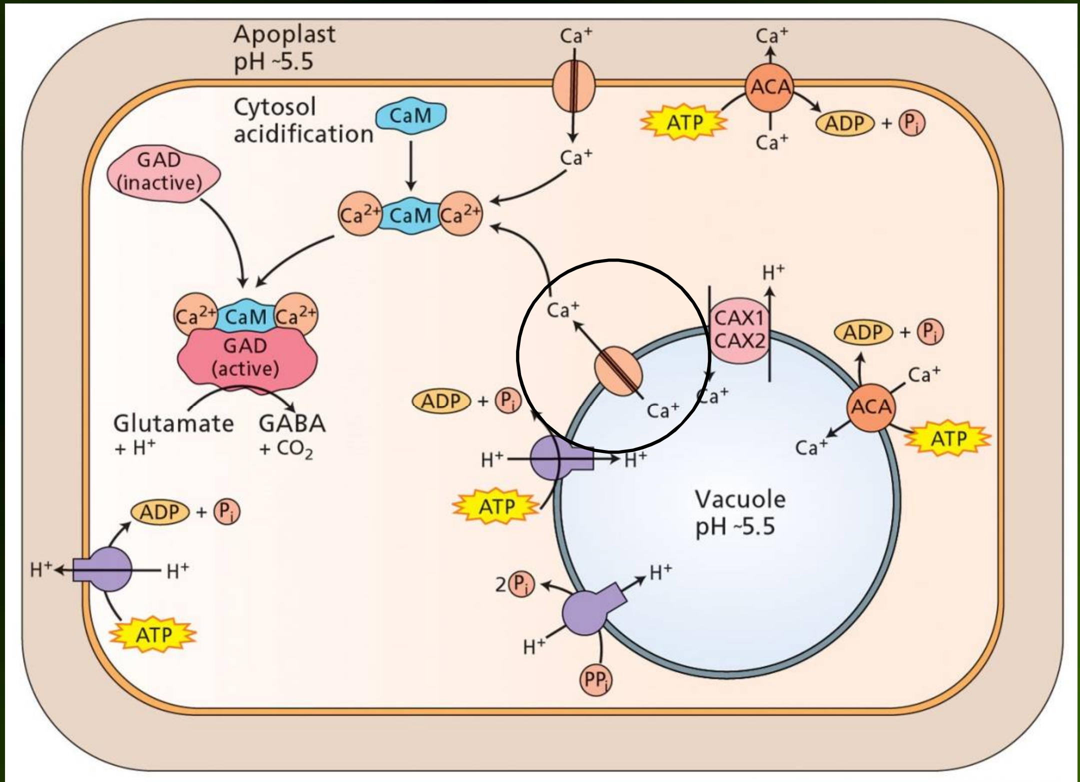
Activation of GAD

↓

Accumulation of GABA, 6-10x

↓

Function of GABA ??



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PMP

f) Oxygen deficit (hypoxia, anoxia)

At aerobic respiration plant perceives oxygen from soil. Oxygen occurs in soil to the depth around several meters.

At submersion (flooding) the aerial pores in soil are full of water =>
=> oxygen shortage, especially at higher temperature, when consumption of oxygen is high .

Anoxia results in growth reduction and serious damages in agriculture.

- plants sensitive to anoxia – pea
- plants resistant to anoxia – rice – adapted to perceive oxygen by an alternative pathway

Development of anaerobic organisms in soil at anoxia

Energy: NO_3^- → NO_2^- Fe^{3+} → Fe^{2+}

NO_3^- → $N_2O + N_2$ SO_4^{2-} → H_2S

Anaerobic organisms produces bakterial metabolites – acetic acid, butyric acid

↓

- plant growth inhibition
- bad smell of flooded soil

NO_3^- – nitrate

NO_2^- – nitrite

N_2O – nitrous oxide (laughing gas)

N_2 – nitrogen

SO_4^{2-} – sulphate

H_2S – hydrogen sulfide

Fe^{3+-} – trivalent iron

Fe^{2+-} – bivalent iron

COP - critical oxygen pressure – oxygen pressure at which speed of respiration is for the first time decelerated by oxygen deficit

Root tips – highly active => respiration speed high, high oxygen pressure

Old root zones – mature vacuolized cells => respiration speed is low, low oxygen pressure

Concentration of O_2 < COP → Middle of root - anoxic or hypoxic

- stopping of electron transport
- stopping of oxidative phosphorylation
- stopping of Krebs cycle

Krebs cycle (citrate cycle) – rise of NADH by oxidation of acetyl groups to CO_2; NADH (like $FADH_2$) – carrier of high-energy electrons and protons; energy stored in these electrons is used for ATP synthesis during process of oxidative phosphorylation (transfer of e^- on O_2, rise of ATP from ADP and P)

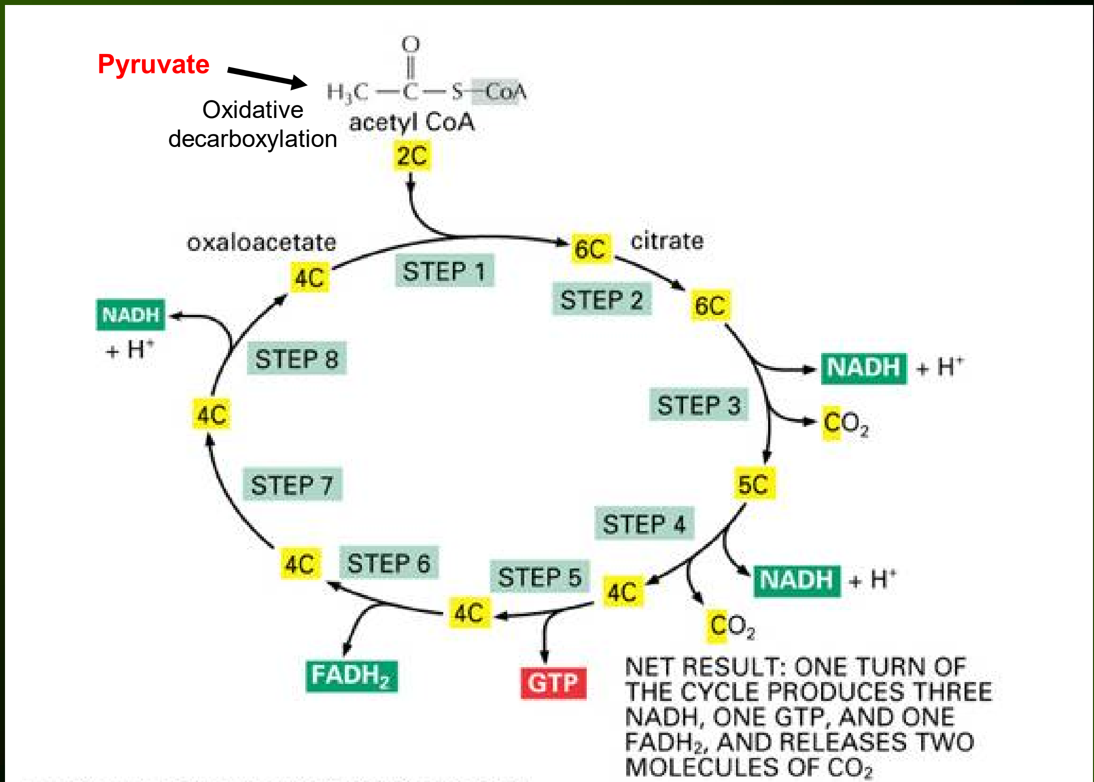


Figure 13-11 Essential Cell Biology, 2/e. (© 2004 Garland Science)

Molecules formed in the Krebs cycle:

2 molecules of CO_2

3 molecules of NADH

1 molecule of GTP

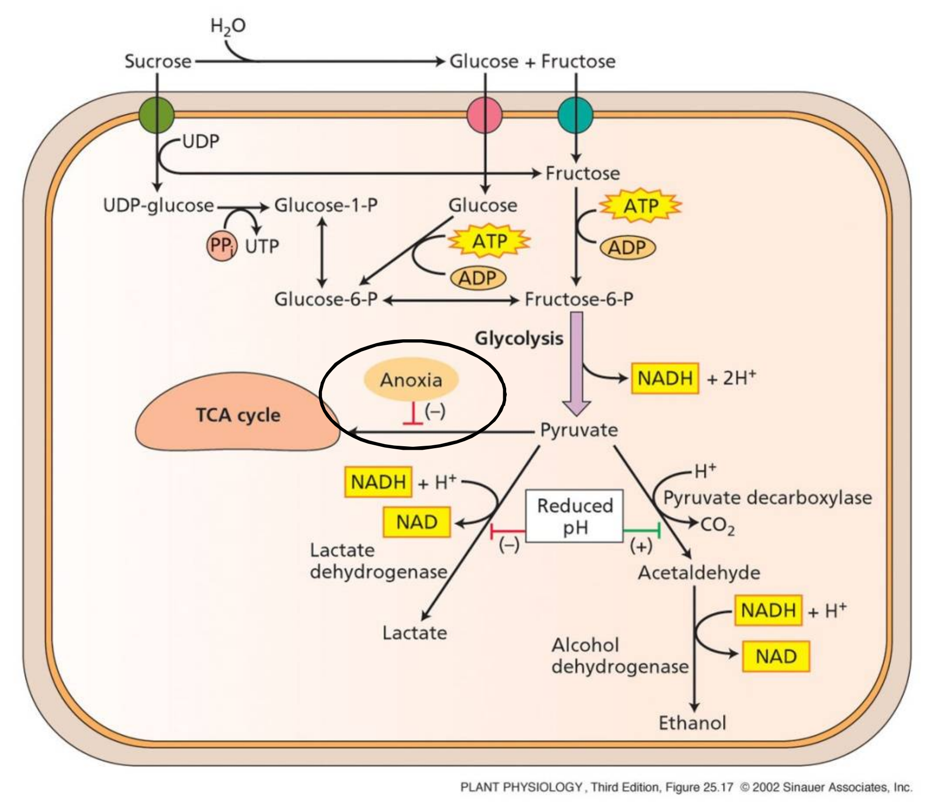
1 molecule of $FADH_2$

NADH – nicotinamide adenine dinucleotide

$FADH_2$ – reduced flavin adenine dinucleotide

PMP

In the case of oxygen deficit, transfer of e$^-$ on O_2 cannot be realizes => no oxidative phosphorylation => no rise of ATP. ATP can be produced by fermentation of pyruvate.



Roots ferment pyruvate first using lactate dehydrogenase (LDH)
- lactic fermentation

Production of H^+ in glycolysis results in decreasing of pH => LDH subsides to work

Low pH activates pyruvate decarboxylase

Alcohol fermentation

2 moles of ATP from 1 mole of hexose

Aerobic respiration:
36 moles of ATP from 1 mole of hexose

Anoxia – shortage of ATP

Alcohol fermentation – high use of H^+ => increasing of pH

ability to overcome anoxia ⇐ lactic fermentation

Anoxic or hypoxic roots do not have enough energy to support physiological processes taking place in stem.

Inability of roots to absorb minerals and transport them into xylem results in ion shortage in leaves => precocious senescence

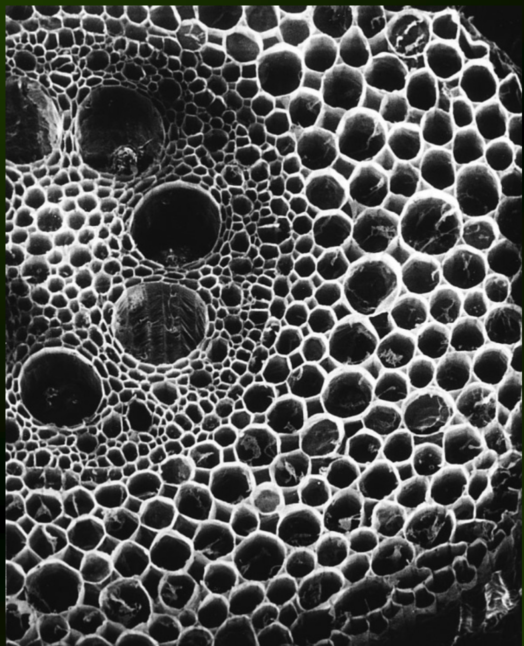
Hypoxia stimulates production of ACC (precursor of ethylene) in roots. ACC is transferred to xylem, where is converted to ethylene.

Anoxia induced by flooding stimulates production of ABA, which is transported to leaf and induces closure of stomata.

Substitute ways of oxygen receipt at anoxia

- in submerged parts of plants endogenous ethylene induces leaf petiole elongation => leaf is getting to the surface => receipt of oxygen (e.g. rice)

- Formation of aerenchyma – hypoxia in roots stimulates ethylene formation. Ethylene increases cytosolic concentration of Ca^{2+}, which induces death of some cells in cortex, their separation and formation of aerenchyma.



Signaling pathway of anoxia perception – little known

Oxygen deficit

↓

Intracellular Ca^{2+} ↑

↓ ?

mRNA ↑

alcohol dehydrogenase,
sucrose synthase

↓

Tolerance to anoxia