Algae & cyanobacteria in extreme environment

Prokaryotic and eukaryotic phototrophs in extremes of

- Temperature
- Salinity
- Low & High pH
- Radiation

Algae & cyanobacteria in extreme environment

- Extremophiles
  - Organisms with optimal growth conditions found beyond “normal” environment (Kristjansson & Hreggvidsson 1995).
    - “normal” envoronment
      - » Temp. 4 – 40°C
      - » pH 5 – 8.5
      - » Salinity betw. that of freshwater and seawater
- Thermophiles, Psychrophiles, Halophiles, Acidophiles, Alkaliphiles, Radiation-resistant oxygenic phototrophs

Thermophilic phototrophs

- Photosynthesis – not compatible with high Temp
- Archeal life – up to 114°C or higher
- Heterotrophic eubacteria – up to 95 °C
- Thermophilic cyanobacteria – up to 74 °C
- Eukaryotic phototrophs – up to 57 °C

Thermophilic phototrophs

Prokaryotic

- hot springs, geothermal areas (max for cyanob. 74°C)
- unicellular – *Thermosynechococcus* (max. 73-74°C)
- filamentous – *Mastigocladus laminosus, Phormidium sp., Oscillatoria sp.*) max. 55-64°C

Eukaryotic

- *Cyanidium caldarium* 45-57°C (pH 2-4, atmosph. pure CO_2)

Psychrophilic phototrophs

- Arctic & Antarctic zones, high altitudes
- low water T phytoplancton, in & on ice, in freshwater , saline streams & lakes, within rocks
- relat. high diversity (low temp. potentially cause no specific problems for photosynth. function)
  - regul. lipid composition of membranes to adjust fluidity -> func. till cytoplasmic water unfrozen

Psychrophilic phototrophs

Prokaryotic

- unicellular & filamnetous cyanob.
  - ice-shelf mats – *Oscillatoria, Nostoc*
  - ice-bound pools – *Oscillatoria, Lyngbya, Phormidium*
  - freshwater – *Phormidium, Synechococcus*
- not true psychrophiles (growth optimum 15-35°C)
- survival = toleance to high light, UV, desiccation
- in marine Arcitic& Antarctic env. - rare

Psychrophilic phototrophs

<u>Eukaryotic</u>

- red, pink, green, yellow patches on melting snow
- snow algae, *Chlamydomonas nivalis*
- “water-melon snow” = *Chloromonas, Ankistrodesmus, Raphidonema, Mycanthococcus*
- *main activity in spring & summer*
- *abundant in marine Arctic&Antarctic env.*
  - ice-shelf diatoms – *Nitzschia, Pinnularia, Navicula*

Halophilic phototrophs

- may thrive at NaCl conc. up to saturat.
- salt lakes, hypersaline lagoons

Prokaryotic

- filamentous – *Microcoleus chthonoplastes* (up to 220g/l)
- unicellular – *Aphanothece, Phormidium, Spirulina*
- maintain intracellular ionic conc. at relat. low level; for osmotic equilibrium organic solutes are accumulated (sucrose, trehalose, glucosylglycerol)

Halophilic phototrophs

Eukaryotic

- *Dunaliella* var.sp. – var. conc. tolerate up to 330g/l
- Na^+ is effectively excluded from cells
- K^+ is accumulated
- for osmotic balance glycerol is accumulated
  - changes in metabolism & affinity of enzymes to glycerol, low membrane permeability to glycerol

Acidophilic phototrophs

- sulfataric fields (Naples Italy; Iceland; Yellowstone)
- need to protect chlorophylls, DNA, ATP,..(unstable at low pH)
- maintain intracellular medium at pH neutral
  - surface barrier extremely impermeable to protones; +other mechanisms *e.g.* protone pumps

<u>Prokaryotic</u>

- cyanobac. generaly pH neutral to alkaline
- filamentous – *Oscillatoria, Spirulina*
- unicell. – *Aphanocapsa, Chroococcus*

Acidophilic phototrophs

Eukaryotic

- *Cyanidium caldarium* (thermoacidophil, Rhodophyceae)
    - tolerate 1N H_2SO_4, growth optimum pH 0-4
- *Dunaliella salina, Chlamydomonas acidophila, Pinularia*
- maintain intracell. pH near neutral
    - var. mechanisms – protone pumps, accumulation H_2SO_4 in vacuoles (pH 0.5)

Acidophilic phototrophs

Table 1. Intracellular pH values measured in *Cyanidium caldarium* and in acidophilic chlorophytes. Data were derived from Seckbach (2000a), Beardall and Entwisle (1984), and Pick (1999)

Alga	External pH	Internal pH
Cyanidium caldarium	2.1	6.6
Chlorella saccharophila	4.0	7.1
Chlorella vulgaris Beij	5.3	6.6
Chlorella pyrenoidosa Chick	3.1	6.6–7.4
Chara corallina Klein ex Wild	4.5	7.3
Scenedesmus quadricauda (Turp.) Breb	3.1	6.8–7.0
Euglena mutabilis Schmitz	2.8	5.0–6.4
Dunaliella acidophila	0.5–3.0	6.2–7.2

Alkaliphilic phototrophs

- photosynthetic CO_2 consumption leads to increase pH in most phototrophs up to pH 9-10 during day
- alkaline lakes, soda lakes
- mechanism – info about halophills
  - limited info on adaptations to high pH

Alkaliphilic phototrophs

Prokaryotic

- soda lakes
- *Spirulina platensis* (pH 11)
- *Microcystis aerugnosa* (pH 10)
- *Plectonema nostocorum*
  (pH 13; 80%max.growth at pH 11)

Eukaryotic

- diatoms *Cyclotella, Nitzschia, Coscinodiscus, Navicula*
- spec. of *Nannochloris, Chlamydomonas, Dunaliella*
- unknown mechanism of adaptation

Radiation-resistant phototrophs

- photosynthesis -&- light
- high light intens.; UV radiation (affects aminoacids, DNA,..)
- protection
    - active – moving away
    - passive – protective compounds
  - Carotenoids
    - quench excited singlet oxygen
    - absorb visible light above 400nm
    - UV protection – indirect
  - mycosporine-like aminoacids – MAAs
    - var. derivates absorb at 310, 320, 360nm

Radiation-resistant phototrophs

<u>Prokaryotic</u>

- cyanobacteria in Antarctica – *Nostoc, Synechococcus*
  - protection - carotenoid pigments (canthaxanthin, myxoxanthophyll),
    -MAAs – intracell.& extracell.
    -alkaloid (scytonemin)
  - mechanisms to repair UV-induced damage

Radiation-resistant phototrophs

Eukaryotic

- *Dunaliella salina* (β-carotene – 8-12% DW)
- *C. nivalis* (astaxanthin)
- aplanospores of snow algae (falvonoids as antioxidants)
- MAAs sunscreens widely found (UV absorb.)
  - *dinoflagellates, cryptomonades,…*

Table 2. Oxygenic photosynthesis in extreme environments: comparison of the abilities to prokaryotic and eukaryotic microorganisms to live under different environmental extremes. For details see Sections 4–9

Environmental parameter	Potential of photosynthetic microorganisms	
	Prokaryotes	**Eukaryotes**
High temperature	Unicellular cyanobacteria (*Synechococcus* [*Thermosynechococcus*] sp.). photosynthesize up to 73–74°C, the highest temperatures enabling photosynthesis	The most thermotolerant eukaryotic alga (*Cyanidium*) is capable of photosynthesis up to 57°C
Low temperature	Cyanobacteria are abundantly found in the Arctic and Antarctic, and grow slowly at near-freezing temperatures. They are psychrotolerant rather than truly psychrophilic	Eukaryotic algae, especially diatoms and green algae, grow in the cold ocean in or around sea ice; snow algae develop in melting snow, and may be true psychrophiles
High salt concentration	Cyanobacteria are abundantly found at high salt concentrations, but seldom develop massively at salt concentrations above 250 g l^{-1}	Unicellular green algae of the genus *Dunaliella* are found worldwide at salt concentrations up to NaCl saturation
Low pH	Cyanobacteria are seldom, if at all, found in acidic environments	Specialized acidophilic photosynthetic eukaryotes (*Cyanidium*, *D.acidophila*) grow at pH values as low as 0–1
High pH	Cyanobacteria, especially *Spirulina*, occur massively in alkaline lakes, some of them are obligate alkaliphiles	Many eukaryotic algae grow in high pH environments
High radiation levels	Cyanobacteria are often found in high radiation environments and tolerate high levels of visible and ultraviolet radiation	Some carotenoid-rich eukaryotic microalgae grow in high light environments