Extremophilic Phototrophs: Thermo-acidophiles

GENOTYPIC AND PHENOTYPIC VARIATION AMONG
THE THERMO-ACIDOPHILIC ALGAE OF YELLOWSTONE
NATIONAL PARK and OTHER GLOBAL LOCATIONS
GENERAL CHARACTERISTICS OF THE CYANIDIALES

- Unicellular red algae (but no phycoerythrin)
- Asexual !!!!!, but 1.3 Ga old
- Includes three recognized genera: *Cyanidium, Galdieria, and Cyanidioschyzon*
  “the cyanidia”
- Live in extreme environments that combine low pH (0.1-4.0) with high temperatures (40-56°C)---no other phototrophs

(These thermo-acidophiles occur in warm acid, volcanic waters globally (e.g. North America, Japan, Kamchatka, Indonesia, New Zealand, Italy, Azores, Iceland)
Questions asked in this “CYANIDIAL” PROJECT (still in progress)

• How much biodiversity occurs within a single “province” (i.e. the geothermal region of Yellowstone National Park)?

• How much greater is global biodiversity?

• Has long-term geographic separation resulted in recognizable speciation?

• How may “cyanidia” disperse successfully?
A member of the Cyanidiales
PC = phycocyanin
C = chlorophyll a

Wild type
PC

From: Lin et al. 1990
Pl. Physiol. 93: 772-777
Table 2. Some values of internal vs. external pH values for Prokaryotes and Eukaryotes.

<table>
<thead>
<tr>
<th></th>
<th>External pH</th>
<th>Internal pH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Archaea and Bacteria</strong></td>
<td></td>
<td></td>
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<tr>
<td><em>Thermoplasma acidophilum</em></td>
<td>2.0</td>
<td>6.0</td>
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<tr>
<td><em>Sulfolobus acidocaldarius</em></td>
<td>2.5</td>
<td>6.0</td>
</tr>
<tr>
<td><em>Bacillus acidocaldarius</em></td>
<td>3.0</td>
<td>6.3</td>
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<tr>
<td><strong>Algae</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cyanidium caldarium</em></td>
<td>2.1</td>
<td>6.6</td>
</tr>
<tr>
<td><em>Chlorella saccharophila</em></td>
<td>4.0</td>
<td>7.1</td>
</tr>
<tr>
<td><em>Chlorella vulgaris</em></td>
<td>5.3</td>
<td>6.6</td>
</tr>
<tr>
<td><em>Chlorella pyrenoidosa</em></td>
<td>3.1</td>
<td>7.0</td>
</tr>
<tr>
<td><em>Chara corallina</em></td>
<td>4.5</td>
<td>7.3</td>
</tr>
<tr>
<td><em>Scenedesmus</em></td>
<td>3.1</td>
<td>6.9</td>
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<td><em>(Turp.) Breb.</em></td>
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<tr>
<td><em>Euglena mutabilis</em></td>
<td>2.8</td>
<td>5.7</td>
</tr>
<tr>
<td><em>Dunaliella acidophila</em>**</td>
<td>(0.5)-3.0</td>
<td>(7.2)-6.2</td>
</tr>
</tbody>
</table>

Adapted from data of Langworthy (1979)*, Beardall and Entwisle (1984)** and Pick (1999)***
Cyanidioschyzon merolae

From: Matzusaki et al. 2004 (the genome paper)  
Nature 428: 653-657

nucleus has about 5,330 genes in 20 chromosomes
The sole Yellowstone Types based on 18S & rbcL:

- **Type II**: *Galdieria sulphuraria*
- **Type I (18S & rbcL sequences identical to *C. merolae)*
- **Type IB**: "enigma strain" IA
- **C. merolae**

10 µm
Thermoacidophilic Red Algae
3 genera and at least 4 species

Galdieria sulphuraria
Spherical cells, 3-9 μm
Grows readily under dark heterotrophic conditions

Cyanidium caldarium
Spherical cells, 3-7 μm
Restricted to acidic thermal sites

Cyanidioschyzon merolae
Crescent, elliptical, or club shaped cells, 1-4 μm
Strict autotroph

Galdieria maxima
Larger cell size, 10-16 μm
Grows slowly under dark heterotrophic conditions

(Species and genera based on morphological characters)
Norris Geyser Basin, YNP--mostly acid waters & sediments
Lemonade Creek, pH 2, 50° C site

Zygogonium (< 35 ° C)

“cyanidia”
Inhibition by UV in Lemonade Creek, YNP
YNP Nymph Creek, pH 3, ~ 48°
“cyanidida” in steam
Sulfide $\Rightarrow$ $\text{H}_2\text{SO}_4$

YNP