Albino leaves in *Sequoia sempervirens* show altered anatomy and accumulation of heavy metals
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**Introduction:**
Redwoods often reproduce vegetatively and occasionally the vegetative shoots are chlorophyll-deficient ("albino"). Lacking chlorophyll, they are thought to be dependent on normal, green portions of the plant. Some leaves are fully albino, some fully green, and others, on occasion, are split (Fig. 1).

**Research Question:**
How do "albino" redwood leaves differ from "normal" green leaves in their anatomy and chemical composition?

**Methods:**
- Adjacent green and white foliage was collected from 11 sites in Sonoma and Santa Cruz Counties.
- Live split leaves (Fig. 2) were sectioned and stained with iodine to indicate starch in plastids.
- White and green leaves were fixed, embedded in resin, sectioned at 3 µm, and stained with toluidine blue for microscopic examination.
- ICP Spectrometry was used to determine elemental concentrations of 11 elements in white and green leaves.

**Results:**
1. Anatomical differences:
   - In split needles, plastids (leucoplasts) in white cells appear more variable in size and shape than plastids (chloroplasts) in neighboring green cells. Both appear to contain starch (Fig. 3).
   - Palisade parenchyma cells are more evident in green leaves than white (Fig. 4, 5).
   - Cell wall structure appears remarkably different in white and green leaves. Epidermal and hypodermal cell walls especially are much thicker in green leaves and lack secondary thickening in white leaves (Fig. 4, 5).
2. Chemical differences (Table 1, Fig. 6):
   - For most elements, mean concentrations in white leaves differed significantly from green leaves.
   - Mean concentrations of Cd, Ni, and Cu in white leaves are over twice as high as in green leaves.
   - Mean Mg concentrations were nearly identical in white and green leaves.

**Discussion:**
- Nickel concentration is normally between 0.05 and 10 ppm in plant leaves, and can begin to be toxic at levels over 10 ppm\(^1\). White leaves have, on average, more than double "normal" amounts. This may cause Ni toxicity symptoms to occur.
- Plastid size and shape was highly varied in white cells as compared to green. Ni toxicity is known to disrupt chloroplast development and structure\(^2\) and may be implicated. Since the plastids in white cells are not photosynthetic, the presence of starch in those plastids indicates importation and storage of sugars from elsewhere in the plant.
- The cell walls in albino leaves are thinner and less developed than those in green leaves. Ni toxicity disrupts cell wall lignification\(^2\) and could be implicated here as well.
- Although chlorophyll contains Mg, there are, unexpectedly, nearly identical concentrations of Mg in leaves with and without chlorophyll.
- A possible mechanism for increased uptake of many micronutrients could be the known higher transpiration rates of albino leaves\(^3\). With significantly higher accumulation of Cd, Ni, and Cu, could the white tissues act as a repository for potentially harmful ions and thereby benefit the rest of the plant?

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**Table 1: Elemental Concentrations (mg/kg dry weight)**

<table>
<thead>
<tr>
<th>Element</th>
<th>White</th>
<th>Green</th>
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<tbody>
<tr>
<td>Ca</td>
<td>4673 ± 915</td>
<td>6243 ± 997</td>
</tr>
<tr>
<td>Cd</td>
<td>0.013 ± 0.149</td>
<td>0.128 ± 0.021</td>
</tr>
<tr>
<td>Cu</td>
<td>20.6 ± 1.0</td>
<td>10.0 ± 1.1</td>
</tr>
<tr>
<td>Fe</td>
<td>112 ± 14.6</td>
<td>94.9 ± 28.7</td>
</tr>
<tr>
<td>K</td>
<td>5225 ± 2183</td>
<td>1807 ± 2961</td>
</tr>
<tr>
<td>Mg</td>
<td>238 ± 178</td>
<td>530 ± 252</td>
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<tr>
<td>Mn</td>
<td>121 ± 16</td>
<td>106 ± 36</td>
</tr>
<tr>
<td>Ni</td>
<td>34.8 ± 8.4</td>
<td>14.9 ± 3.6</td>
</tr>
<tr>
<td>P</td>
<td>4500 ± 335</td>
<td>2924 ± 333</td>
</tr>
<tr>
<td>S</td>
<td>1987 ± 82</td>
<td>1406 ± 116</td>
</tr>
<tr>
<td>Zn</td>
<td>55.2 ± 2.8</td>
<td>49.6 ± 7.9</td>
</tr>
</tbody>
</table>

**References:**

**Figure 1: White, Green, and Split Leaves**

**Figure 2: Split Leaf Cross Section**

**Figure 3: Plastid Comparison**

**Figure 4: White and Green Leaves Anatomical Comparison**

**Figure 5: White and Green Epidermis/Hypodermis Comparison**

**Figure 6: Elemental Concentrations in White Leaves Relative to Green Leaves**