LEDs to Replace Fluorescent Tubes for Growth of Cultured Algae

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LEDs to replace fluorescent tubes for growth of cultured algae.

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The Issue. Fluorescent bulbs are widely used for algal culture stocks and production in aquaculture operations. Metal halide lamps are also used for production tanks with significant electricity demand and heat production. LED technology promises lower operational costs with less energy waste as heat for equivalent light energy production. Re-tooling algal production facilities with new LED fixtures incurs significant expense that must be recaptured in savings over time. The initial cost, added to concerns over the unknown response of algae to LED light sources may both be factors inhibiting incorporation of this new technology. LED replacement tubes are available to retrofit fluorescent tube fixtures and may offset some conversion costs to replacing light sources. Concerns about the ability of LEDs to provide adequate algae production for hatchery operations led us to run side by side comparison of growth dynamics for four commonly used algae strains using fluorescent light and LED replacement tubes. We also implemented a tunable red and blue LED unit for mass algae production in tanks.

Lighting. Existing 4 ft T12 fluorescent tube banks (Philips 40-Watt ALTO Supreme Linear T12 Fluorescent Light Bulb, Cool White 4100K) in multiple shelf carboy systems at the Castagna Research Hatchery were used for the comparison. Direct wire LED tubes were used in the existing 4 ft T12 fluorescent fixtures (Envirolight, Altech Corp, CA). Necessary modifications will vary based on the existing fluorescent fixtures, we changed shunted tombstone electrode fittings to non-shunted tombstones and bypassed the ballast. Special care should be taken when retrofitting LED bulbs into existing fixtures and modifications should follow manufacturer’s recommendations along with UL standards (UL 1598C). Complete units for replacing fluorescent strip fixtures or new installation are available from multiple sources, e.g., Envirolight 4 ft, 2 bulb T8 industrial LED strip units with 1800 lumen tubes ($35.00 in 2018).

The LED tubes had a greater quantum yield than the fluorescent tubes in use, so only two LED tubes were used, matched with four fluorescent tubes. Black plastic mesh was used as a neutral density screen material to further reduce the LED light output to match that of the fluorescent tubes. LED light was adjusted to the equivalent LUX output of the 4 bulb fluorescent tube bank using a Fisherbrand™ Traceable™ Dual-Range Light Meter. Energy output in μmoles m⁻² sec⁻¹ was recorded with a Li-Cor LI 1500 meter with cosine sensor. Light energy output from two of the fluorescent tubes at 6 inches was ~ 45 μmoles m⁻² sec⁻¹. Output from two of the LED tubes at 6 inches was ~ 80 μmoles m⁻² sec⁻¹. A LumiGrow Pro 650 LED light bank was also used for mass algae growth in two 750 L tanks, with red and blue LED illumination at ~100 μmoles sec⁻¹ m⁻¹ at the surface.

Algae Cultures. The algae used are listed in Table 1. Commercially available F/2 algae medium (plus silica for Chaetoceros) in filtered and UV treated Wachapreague Channel water was used for all cultures. Starter cultures (500 ml) were grown in one liter flasks under white fluorescent lighting. Cultures for the experimental comparison were grown in polycarbonate 20 liter carboys fitted with polyurethane foam plugs and filtered air for mixing delivered to the bottom by glass tubing. Carboys were bleached and acid washed prior to use. Temperature for the experiments ranged from 19.5 to 22.8 deg C.
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Table 1. Species used for comparing fluorescent vs LED lighting. Regression equations to relate absorbance to cell counts were based on dilutions of stock cultures and hemocytometer counts.

<table>
<thead>
<tr>
<th>Algae species</th>
<th>Absorbance @ 650 nm vs cell count equations</th>
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<tbody>
<tr>
<td>Chaetoceros calcitrans</td>
<td>Cell count = 3.9609 * absorbance - 0.0126</td>
</tr>
<tr>
<td>Pavlova pinguis CCMP 459</td>
<td>Cell count = 9.9482 * absorbance - 0.1483</td>
</tr>
<tr>
<td>Isochrysis sp. (Tahiti)</td>
<td>Cell count = 7.0946 * absorbance - 0.1285</td>
</tr>
<tr>
<td>Tetraselmis chui - PLY 429</td>
<td>Cell count = 2.074 * absorbance + 0.0313</td>
</tr>
</tbody>
</table>

Results. No significant differences were found for any of the algal species tested based on cell counts, pH as a measure of photosynthetic activity, total chlorophyll as a measure of photosynthetic biomass, and absorbance as a measure of overall biomass. We did not compare biochemical composition of the cultures (lipids, carbohydrates, proteins).

Based on output alone, one LED tube would approximate 2 white fluorescent tubes. Although fluorescent tubes are cheaper initially, operational costs and lifetime of bulbs and ballasts may make off the shelf LEDs a more favorable economic choice, and may provide some spectral advantages (see below).
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It should be noted that these trials were conducted at relatively low light levels, matching existing culture conditions of the Castagna Research Hatchery. Higher light levels are common in commercial hatcheries and results may differ as light saturation points are reached. For the diatom *Skeletonema costatum*, the lowest wavelength-specific saturation found was for blue light, ~ 40 µmoles m\(^{-2}\) sec\(^{-1}\), and corresponded to the greatest absorption efficiency (Miao et al., 2012). For *Isochrysis affinis galbana*, no photoinhibition was observed up to 450 µmoles m\(^{-2}\) sec\(^{-1}\) (Marchetti et al., 2012). The saturation limits for illumination and any photoinhibition that may occur with at high light intensities was not examined in our trial and may be explored in the future.

**Spectral quality.** The LED units tested were designed for off the shelf inexpensive general lighting, yet may provide broader spectral coverage than standard fluorescent tubes. The absorption spectrum for chlorophyll has peaks in the red and blue wavelengths (Figure 8). Standard fluorescent tubes have narrow peaks in blue and red (Figure 9) but are the opposite of the magnitude of blue and red absorption of Chlorophyll (Figure 8). The white LED bulbs have a large peak emission in the blue and are weaker in the red, but more closely match the absorption spectrum for chlorophyll, and provide coverage of other wavelengths more similar to daylight.

Our measured growth performance under these two different light sources at relatively low light levels did not show any differences, but spectral effects on biochemical composition in algae production have been noted, especially at below saturation light levels. (Marchetti et al., 2013; Severes et al., 2017; Zhong et al., 2018). Units like LumiGrow use a mix of adjustable blue and red LEDS to match the absorption spectrum of chlorophyll, and are intended to replace metal halide lamps. For a freshwater algae *Chlorella* sp., a blue and red LED combination has been demonstrated to enhance biomass production, and the ability to shift to red at peak biomass production increased lipid content (Severes et al., 2017).

**References**


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Figure 4. Comparison of fluorescent white bulbs with white LED tube replacements for *Chaetoceros calcitrans*. Red symbols are replicates with fluorescent bulbs. Blue symbols are replicates with LED bulbs at equivalent LUX output. Absorbance (lower right) represents total biomass.
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Figure 5. Comparison of fluorescent white bulbs with white LED tube replacements for *Isochrysis* sp. (Tahiti). Red symbols are replicates with fluorescent bulbs. Blue symbols are replicates with LED bulbs at equivalent LUX output. Absorbance (lower right) represents total biomass.
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Figure 6. Comparison of fluorescent white bulbs with white LED tube replacements for *Pavlova pinguis* CCMP 459. Red symbols are replicates with fluorescent bulbs. Blue symbols are replicates with LED bulbs at equivalent LUX output. Absorbance (lower right) represents total biomass.
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Figure 7. Comparison of fluorescent white bulbs with white LED tube replacements for *Tetraselmis chui* - PLY 429. Red symbols are replicates with fluorescent bulbs. Blue symbols are replicates with LED bulbs at equivalent LUX output. Absorbance (lower right) represents total biomass.
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Figure 10. LumiGrow red and blue LED specifications intended to match halide lamp use. From: LumiGrow’s Guide to Specifying LED Lighting. 2013.
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Figure 11. Mass culture tank (~750 L) under a LumiGrow LED fixture. Light energy output at 5 ft was recorded at ~100 µmoles sec\(^{-1}\) m\(^{-2}\), or about half the maximum output of the unit.