Duckweed: A Tiny Aquatic Plant with Enormous Potential for Space Life Support

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DUCKWEED: NUTRIENT DENSE CROP FOR EXPLORATION

Duckweeds (family Lemnaceae) are tiny flowering plants with enormous potential for bioregenerative space life support. Also known as water lentils or water meal, these small angiosperms are gaining global recognition as a powerful and ecologically friendly means of absorbing nutrients from wastewater. In addition, duckweed has a very high nutritional density and little fibrous material, making it a 100% edible and potentially valuable fresh food supplement to crew diets on long-duration exploration missions.

Spirodela (Large), *Wolffia* (Small), and *Lemna* (Medium) – Landesman (2010)

Space Lab Technologies, LLC and researchers in plant biology and aerospace engineering at the University of Colorado at Boulder are working to **establish duckweed as a nutrient dense space crop for deep space exploration**.

WHAT IS DUCKWEED?

- Smallest flowering plant on Earth
- Among the fastest growing plants in the world
- Over 40 species
- Can grow free floating or submerged
- Found in still/slow flowing fresh water
- Common in lakes, ponds, canals, rice fields, ditches, even mud

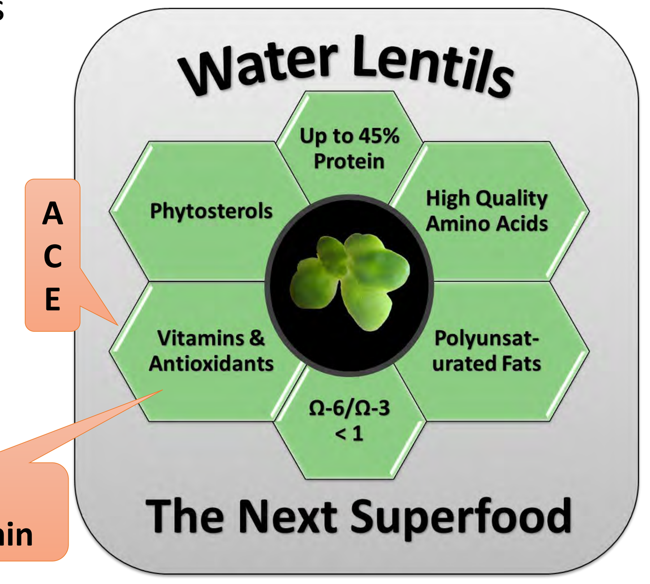
Fronds:

- Oval shaped vegetative bodies
- 1-20 mm across & grow singly or in small groups
- Take up gases and nutrients
- Permanently open stomata on top
- Cutin (waxy, water repellant coating) on top
- Air sacs provide buoyancy
- Vascular system practically absent
- Little structural tissue needed (floating)

Roots: provide mechanical stability

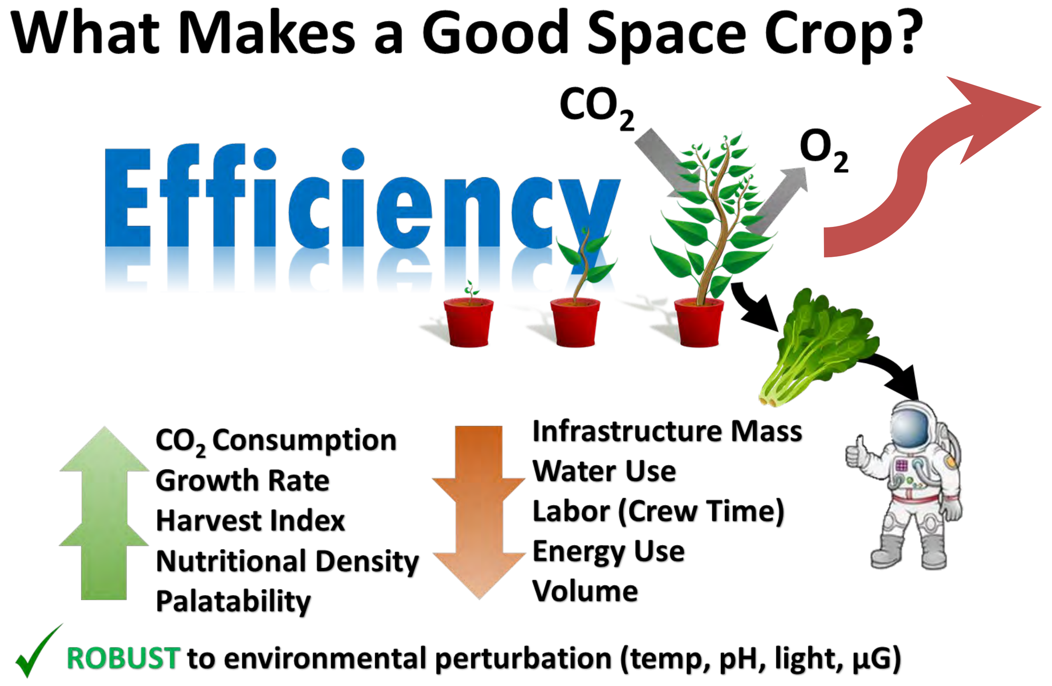
Reproduction:

- Primarily vegetative budding
- Flowering rarely observed
- Up to 10 daughters in 10 days before dying
- Doubles biomass in 1-3 days in ideal conditions



AN ATTRACTIVE PLANT FOR SPACE

What Makes a Good Space Crop?



1. 100% Harvest Index
2. Can be eaten raw
3. Highly nutritious
4. High growth rate
5. Vegetative budding
6. Thrives in high CO_2
7. Grows in 24-hr light
8. Grows in shallow water
9. Environmentally robust
10. Palatable
11. Grows in dark on sugar
12. Has a dormant state
13. Prefers ammonium-N
14. Have been grown in µG

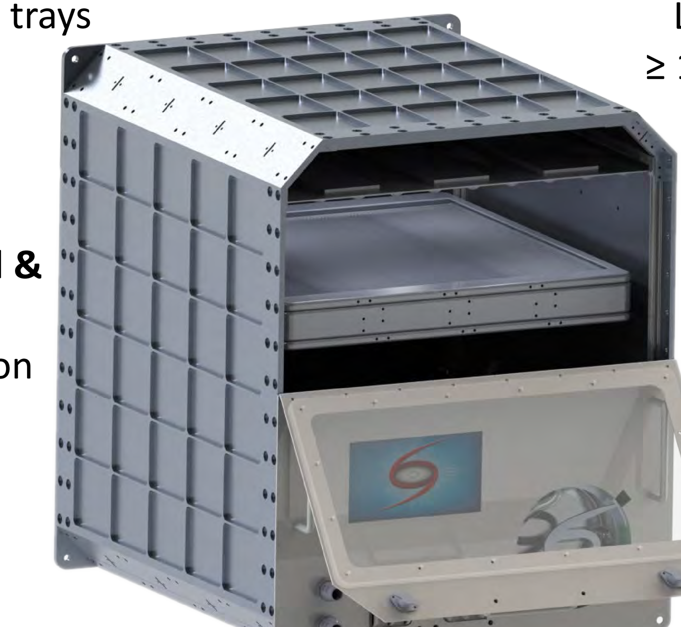
NASA STTR: µG-LILYPOND™: FLOATING PLANT POND FOR MICROGRAVITY

Space Lab, Univ. of Colorado Boulder, Smead Aerospace Engineering Sciences, Refcon Services, Inc., Joe Tanner (Former NASA Astronaut)

Enclosure
22" (L) × 18" (W) × 22" (H)
Dual MLE, with Ortho-Grid

Growth Area
×2 Dual sided 15" × 15" trays
0.6 m^2 Total Area
Vertically Stacked

Close Canopy Lighting
Liquid Cooled LED Panels
≥ 1200 µmol/m/s² | σ = ±10
Uniform Coverage



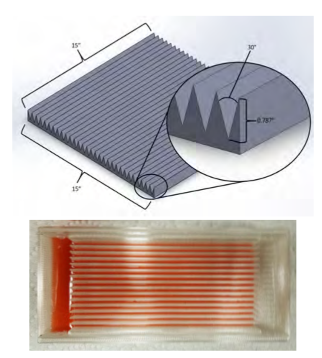
Atmosphere and Thermal & Humidity Control
Direct Cabin CO_2 Utilization
Reduces to O_2
No Latent Heat Load
Heat Rejection via MTL

Command & Data Handling
Space Lab Perseus Lite Processing Unit
for Autonomous Control
Microprocessor & FPGA
Xilinx Artix-7

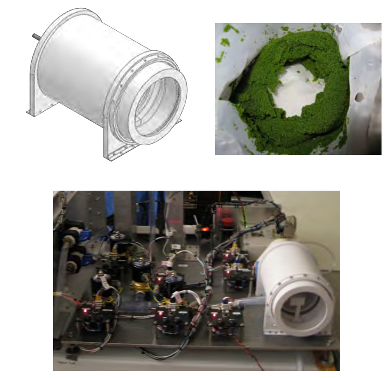
Autonomous Water & Nutrient Recycling
Condensate Recovery
Mass-Balance Nutrient Replenishment

Microgravity Compatible Rotary Sieve
3-Phase Separator
Collects Biomass in Filter Bag

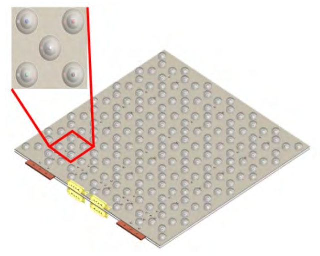
Passively Fed Growth Bed



Biomass Harvest & Effluent Extraction

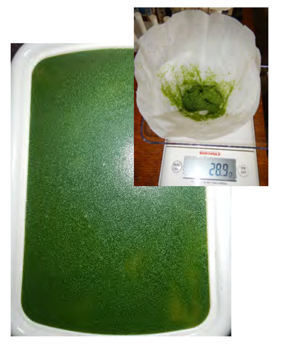


Close Canopy Lighting



Photon Flux Density (PFD) Deviation <10 when 1" from canopy

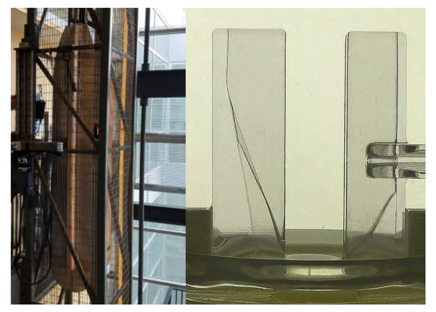
Thin Film Propagation



Growth Area: 0.58 m² (15" × 15" Trays x4) **System Volume: 0.14 m³**
Potential Volumetric Yield: Up to 85 gDM/m3-day (4 times white potato yield)

Upcoming Demonstration Tests:

- **Engineering Demonstration Unit** (EDU) to demonstrate key features in Phase II of STTR
- **Drop tower tests** at Portland State University, to further understand microgravity effects on capillary fed growth bed
- Mid-2020 **sub-orbital flight** aboard the Blue Origin New Shepard to demonstrate water transport, harvest, and growth bed in microgravity.
- **Extensibility**: Investigating hydrophilic membranes with growth bed to support higher rooted plants, like microgreens.



3D-printed (SLA) test article, with interior corner geometry

Hydro-membrane for Plant Cultivation developed by Mebiol, Inc.

Flight Demonstration Planned for mid-2020

TRISH BRASH 1801: CO-OPTIMIZATION OF DUCKWEED YIELD, NUTRIENT DENSITY, & ENERGY USE

Space Lab & Univ. of Colorado Boulder, Department of Ecology & Evolutionary Biology

A LIGHT RECIPE TO CO-OPTIMIZE:

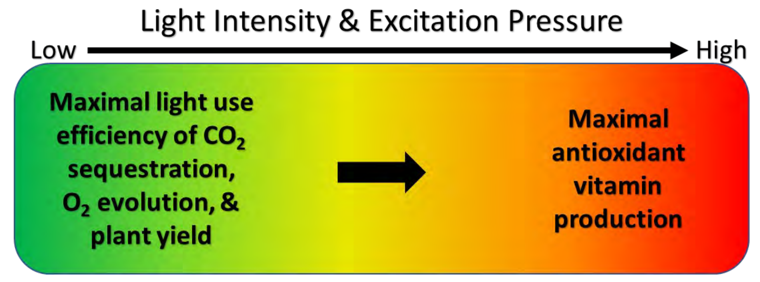
1. Edible biomass yield
2. Micronutrient content
3. Protein content
4. Energy efficiency

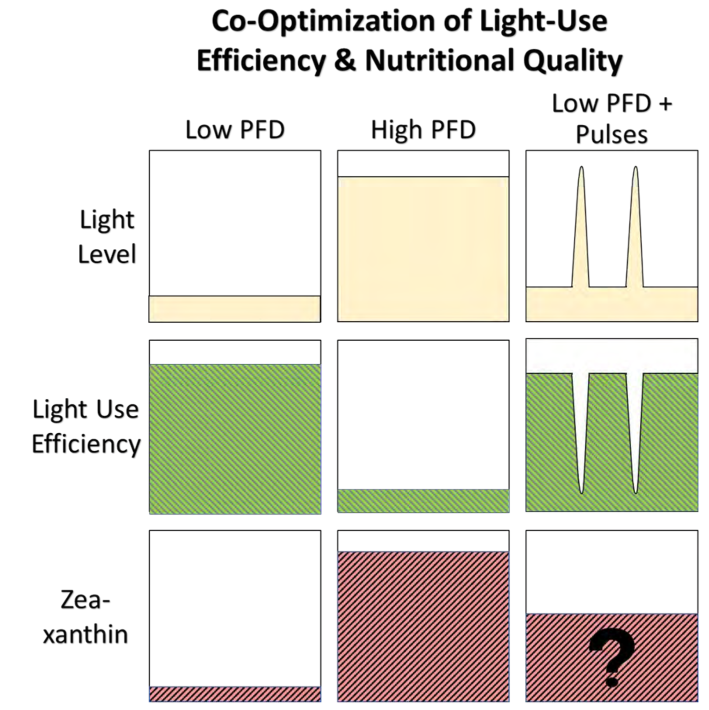
UNDER SPACE RELEVANT CO_2 LEVELS (up to 1%)

A nutrient dense food high in vitamins, antioxidants, and omega-3 fatty acids can combat adverse effects of space radiation for deep space exploration.

Plants growing in the shade of a forest canopy will still make a lot of zeaxanthin if they receive some high-light pulses.

Photograph by WW Adams





Year 1 Preliminary Results: *Lemna gibba* Grown Under Ambient CO_2

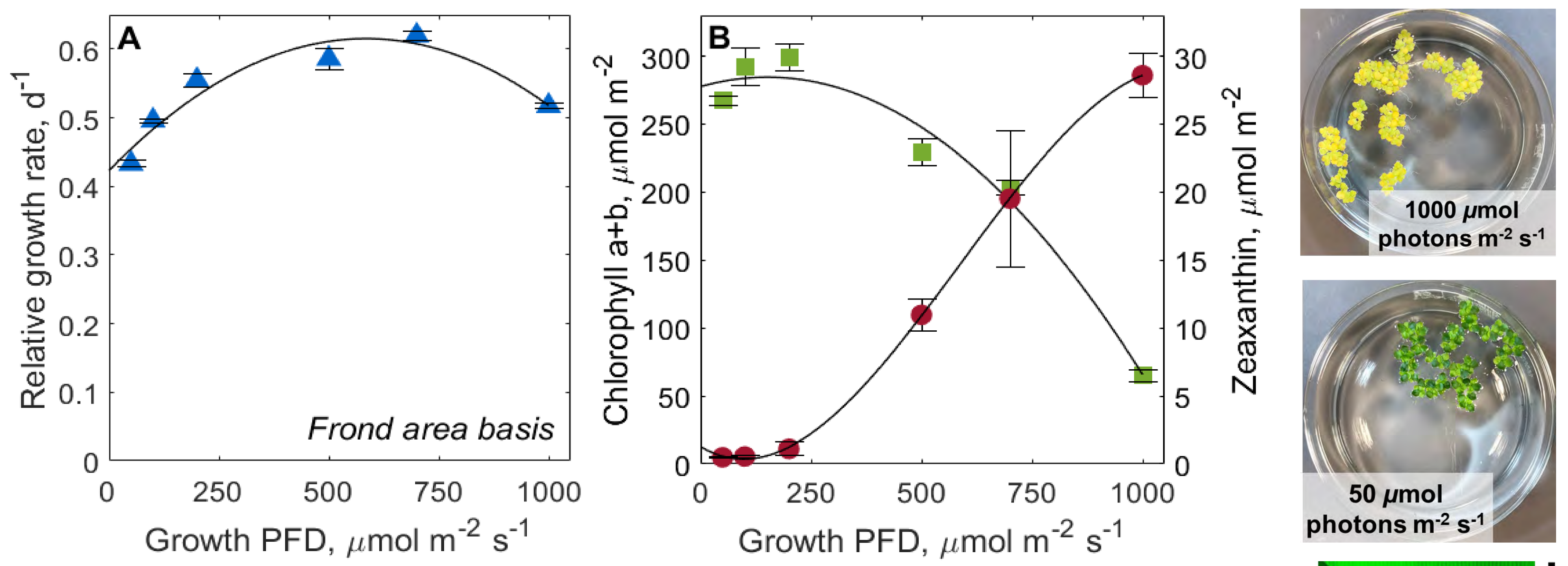
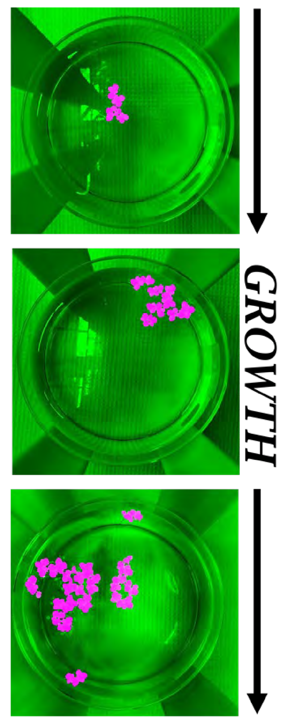


Figure 1. A) Relative growth rate (i.e. rate constant for exponential growth) calculated as $(\ln X_2 - \ln X_1)/T$, where X_2 is the frond area at test end, X_1 is frond area at test start, and T is the test duration. **B)** Content (leaf area basis) of chlorophyll (absorbs light) and the carotenoid pigment zeaxanthin (dissipates potentially damaging excitation energy not utilized in photosynthesis as harmless heat). PFD is the photon flux density of continuous light.

Conclusions & Next Steps:

L. gibba maintains a remarkably constant growth rate over a wide range of light intensities, by increasing light-absorbing chlorophyll under low light supply and increasing antioxidant zeaxanthin for protection against intense light. In Year 2, we will determine the growth saturating PFD for elevated CO_2 levels (up to 1%), validate that pulsed lighting boosts antioxidant production without decreasing growth (at ambient and elevated CO_2 levels), and investigate spectral quality effects on growth and antioxidant production.



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