Vegetable Production Systems Component Tests

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Introduction

As long-term spaceflight missions become ever more imminent, astronaut nutrition and diet require further investigation and development. Dehydrated or stabilized food sources are currently used for spaceflight, but growing fresh produce aboard spacecraft can potentially supplement the astronauts' diets. Further, having astronauts work with plants while in space can provide psychological benefits by serving as a tangible passage of time and representing a living component aboard an otherwise mechanical environment. As spaceflight duration will lengthen as missions head back to the Moon and to Mars, having the ability and knowledge to grow fresh produce will become even more vital. The following experiments were conducted in the late summer and fall of 2018. The purpose of these studies were to examine potential off-gas from a system component that could potentially inhibit plant germination, optimizing lighting methods and protocol for mizuna production, determining a fertilizer method that best promotes healthy mizuna yields, and troubleshooting tomato production for the next generation of the Vegetable Production System.

EXPERIMENT 1 – Label Off-Gas Test

The Vegetable Production System (Veggie) plant growth unit uses customized pillows or Passive Orbital Nutrient Delivery System (PONDS) units to grow vegetable crops aboard the International Space Station (ISS). While pillows have been tested without adhesive labels, the newer PONDS units will require adhesive-applied labels attached to them to identify experiment number, plant number, and crop type. To ensure the labels do not emit volatile off-gases that could inhibit plant growth, a germination study was conducted on two crop species of interest for upcoming Veggie experiments: mizuna (*Brassica rapa* var. *niposinica* L.) and tomato (*Solanum lycopersicum* L.).

For 7 sets of each species, 20 seeds were sealed in gas impermeable Tedlar™ bags with several labels inside for exposure, and 20 control seeds were sealed in Tedlar™ bags without labels. After each month progressed, one set of seeds from each treatment was removed from the bags and tested for germination. Seeds were placed on filter paper in petri dishes; watered with cool tap water to supply calcium, which is helpful for germination; sealed with a plastic paraffin film; and monitored daily until all seeds had germinated or were deemed unviable.

Both crops germinated similarly across treatments, and germination success depended on factors unrelated to the label (Figure 1). Using this label on Veggie PONDS units will not alter experiment success. Moreover, germination rate did not deteriorate over time, which is vital when crops may be stowed for months before testing aboard the ISS begins.

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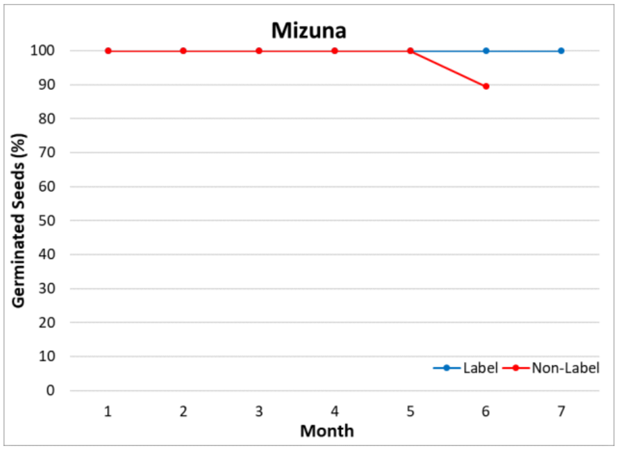

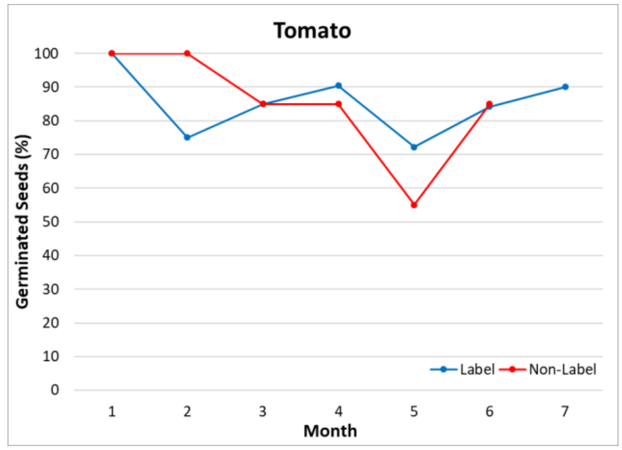

Figure 1. Mizuna and tomato germination across a 7-month period. A set of control seeds not exposed to the labels was not available for the final 7-month test.

EXPERIMENT 2 – VEG-04A EVT

VEG-04 is the first peer reviewed selected Veggie systems experiment with crop plants, and mizuna mustard is the crop of interest. We recently conducted the Experiment Verification Test (EVT) for VEG-04A, set to fly to the ISS in early December 2018. VEG-04A focused on mizuna production under different lighting ratios. One lighting treatment was 90% red : 10% blue, while the other was 50% red : 50% blue. Both treatments also had a small percentage of green light. Blue light increases chlorophyll production, while red light promotes robust growth. The EVT was conducted in a growth chamber with temperature, relative humidity, and CO_2 levels resembling those on the ISS for 28 days (Figure 2).

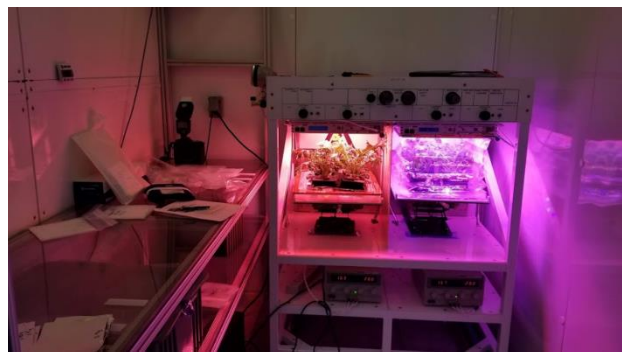

Figure 2 (above). The growth chamber contained a setup similar to flight, with the lighting treatments grown in proximity of one another. Figure 3 (below). Harvesting mizuna on 28 DAP.

One Veggie unit, each containing 6 plant pillows, was used for each light treatment. Plant canopy heights were maintained at 10 cm from the lighting units, and plants were monitored, photographed, and watered regularly. Final harvest assessed plant survival, health metrics, microbiology, and crop yield.

The plants grown for the EVT showed similar total leaf mass across light treatments, and no plants suffered from pathogenic contamination.
While one plant in each Veggie unit died from salt burns caused by contact with the wicking material in the pillows, the experiment was successful overall. The EVT helped modify the watering schedule and amounts the astronauts will give the plants when the study is conducted aboard the ISS in early 2019.

EXPERIMENT 3 – VEG-04B "Cut-and-Come-Again"

VEG-04B will also look at mizuna production, but with "cut-and-come-again" harvesting. In preparation for flight of this test on the ISS, a ground study was conducted in Veggie analog hardware. This study tested the ability to have multiple crop harvests over a 56-day period, while also optimizing fertilizer programs. The four fertilizer programs tested derived from prior mizuna "cut-and-come-again" tests.

Multiple metrics were taken at each harvest date, including total fresh mass. Only large leaves were taken at the 28 DAP and 42 DAP harvests, leaving enough leaf material to keep the plants alive for a final harvest at 56 days. The first harvest was 28 DAP, where fertilizer treatments B (7.5 g L^{-1} 18-6-8 T70 + 5 g L^{-1} 18-6-8 T180) & D (7.5 g L^{-1} 18-6-8 T70 + 5 g L^{-1} 18-6-8 T180 + 1 g L^{-1} 0-0-19 + 9% Mg) were the highest producers of total fresh biomass ($P = 0.02$; Figure 4). Total fresh mass declined across harvest dates ($P < 0.001$) for all treatments, but fertilizer treatment B performed better than treatment A (7.5 g L^{-1} 18-6-8 T70 + 5 g L^{-1} 18-6-8 T100), C (7.5 g L^{-1} 18-6-8 T70 + 5 g L^{-1} 18-6-8 T100 + 1 g L^{-1} 0-0-19 + 9% Mg), or D. Treatment B was also selected based on its overall quality compared to other treatments (Figure 5), with plants generally showing dark green, healthy leaves throughout the growth cycle.

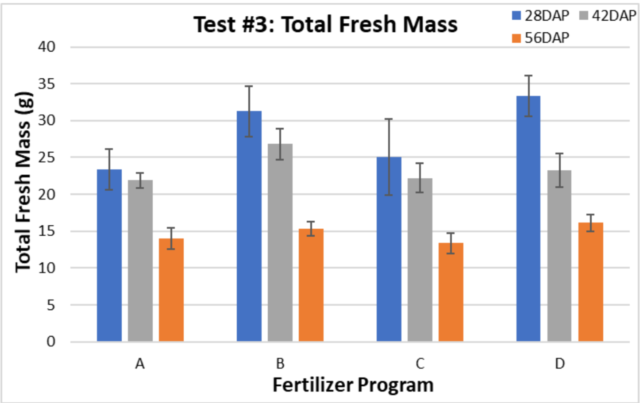

Figure 4. Total fresh mass taken across harvest dates (28 DAP, 42 DAP, and 56 DAP). Bars represent the mass harvested (g), with standard error bars included.

Figure 5. Representative plants from fertilizer treatments A-D (left to right) at the final 56 DAP harvest.

EXPERIMENT 4 – VEG-05 Tomato Production

Fruit production is the next step in achieving space crop production. Veggie pillows have proven successful for leaf crops like those grown in VEG-04, but fruit crops generally require more water than leaf crops. Because fruit crops may surpass the water holding capacity of Veggie pillows, the Passive Orbital Nutrient Delivery System (PONDS) aims to solve this potential structural limitation. The PONDS system is currently being redesigned to solve issues within the system, so a tomato production test was initiated in pillows to test the potential resource limitations of the Veggie pillow system. We selected to use the dwarf "Red Robin" cherry tomato variety for its high yield and compact stature, both ideal for the limited available space in the Veggie system. The Veggie unit included 4 pillows: 2 (250 mL) media capacity pillows and 2 (500 mL) pillows. Within each pillow, 2 tomato seeds were placed at the soil surface between polypropylene-based wicks to increase chances of plant establishment. Water was added to each pillow, and the Veggie system was kept under darkness for 3 days to stimulate tomato germination. The lighting system (90 red : 10 blue; Figure 6) was initiated on 4 days after planting (DAP), wicks were opened to expose the plants, germination was noted at 100%, and each pillow was thinned to 1 plant. This ongoing study requires maintaining the plant canopy at 10 cm from the LED light system, and the pillows are watered every other day to best replicate astronaut activity availability.

Figure 6. Tomatoes inside the Veggie unit with red-enriched lighting.

Although the surviving plants are flowering, two limitations have arisen throughout this study. First, the wicks build up salts that damage leaves and other plant structures when held in contact for an extended period of time. Two tomato plants quickly died from wick-related salt burn (Figure 7). Further investigation prompted by this and related instances is needed to determine better wick opening methods; wicks would potentially attach to the pillows after opening to minimize leaf-to-wick contact while maintaining the wick capillary action benefits.

Water holding capacity of each pillow is the second limitation. The crops are now large enough that they will potentially require more water than what can be held within the pillows while maintaining the every other day water schedule. Thus far, the plants have wilted minimally; the wilting-like appearance of the leaves is actually due to etiolation, caused by the elevated CO_2 within the growth chamber (Figure 8). The PONDS system will hopefully be ready for crop testing soon, but, apart from the wick issue, the Veggie pillow system appears to be a potential backup option for small fruit crop production.

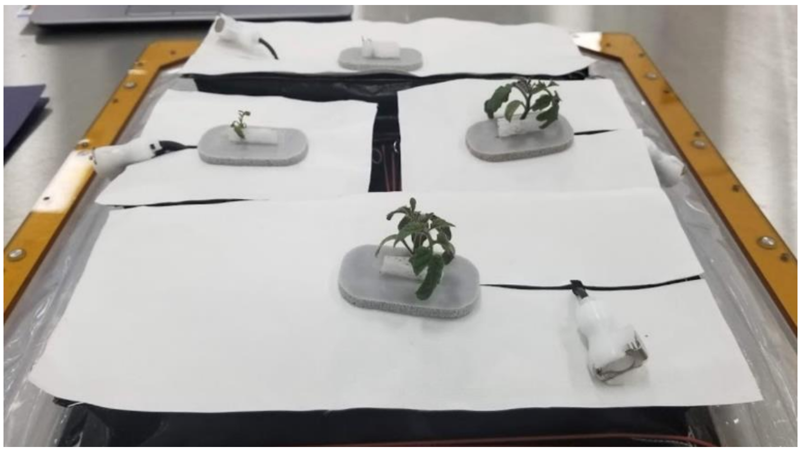

Figure 7. The rear and middle left plants suffered from salt burn caused by the wicks.

Figure 8. Remaining tomato plants flowering.

Conclusion

The experiments tested were all successful or, in the case of Experiment 4, are still ongoing. The label off-gas study determined that this particular label material did not inhibit tomato or mizuna germination. The VEG-04A EVT honed astronaut protocols while determining that the two lighting treatments will be suitable for on-orbit testing. VEG-04B analog testing helped us choose fertilizer treatment B as the best option for future mizuna production. Finally, tomato production in pillows is an option in the absence of PONDS units, although future research is needed to resolve salt burn caused by the wicking material. Many thanks to NASA for funding these studies and to the Veggie team.