Preparation for Pick-and-Eat Food Production on the International Space Station: Flight Definition for the VEG-04 and VEG-05 Missions

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Introduction

This project is a collaboration between Kennedy Space Center, Johnson Space Center, Purdue University, and ORBITEC-SNC. Our aim is to examine the impact of light quality and fertilizer formulation on crop morphology, edible biomass yield, microbial food safety, organoleptic acceptability, nutritional value, and behavioral health benefits.

Lighting Effects on Food Production

The Veggie light cap contains Red, Blue and Green LEDs. Our goal is to determine the optimum ratio for production of salad crops on ISS. To test the impact of lighting on nutritional content, four light regimes are being investigated on the ground, and these will be down selected to two regimes, which will be tested on the ISS. These tests will be done for two different crops – a leafy green crop and a dwarf tomato.

Crop Change

Crops were selected from a broad assessment of eight leafy green and six dwarf tomato varieties conducted in 2014 and 2015. Original plans to use 'Tokyo Bekana' Chinese cabbage as the selected leafy green were modified after severe stress responses (Fig. 1) in this crop were traced to elevated CO_2 levels (Fig. 2). CO_2 on the ISS averages around 2800 ppm and the Veggie hardware does not control this level.

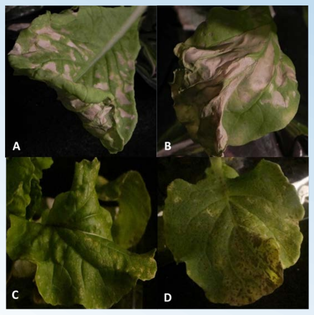

Fig. 1. Stress response in Chinese cabbage grown under four LED light treatments (28d at 330 µmol·m^{-2}·s^{-1}; R=Red, B=Blue, G=Green) and ISS CO_2 levels. **A.** 9R:1B:1G (21d) + 5R:5B:1G (7d) **B.** 9R:1B:1G, **C.** 5R:5B:1G, **D.** 7R:3B:1G.

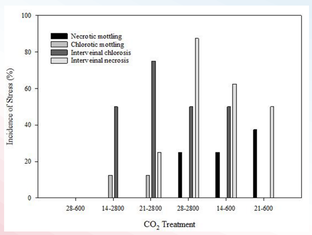

Fig. 2. Incidence of various expressions of crop stress in Chinese cabbage exposed to 6 different duration-CO_2 concentration treatments: 28 days at 600 ppm, 21 days at 600 followed by 7 days at 2,800, 14 days at 2,800 followed by 14 at 600, 28 days at 2,800, 14 days at 600 followed by 14 days at 2,800, 21 days at 2,800 followed by 7 days at 600. Values presented as average proportion of total leaves per plant expressing each symptom.

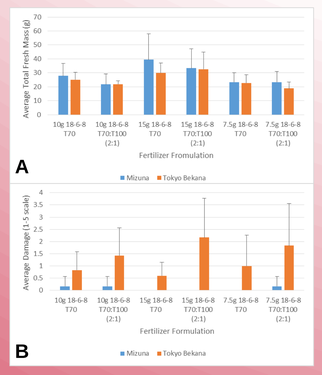

Fig. 3 A. Growth of Chinese cabbage and mizuna plants in Veggie analogs in response to 6 different fertilizer treatments and **B.** Damage assessments of plants at harvest. N=6 plants.

Chinese cabbage was compared to a closely related candidate, mizuna. Mizuna is a crop which showed similar excellent growth and organoleptic characteristics in a preliminary screening. Comparison tests in Veggie analogs show comparable yields to Chinese cabbage but with little observable damage (Fig. 3, Fig. 4).

Fig. 4 Mizuna (L) and Chinese cabbage (R).

Food Safety of Space-Grown Produce

Hazard Analysis and Critical Control Point (HACCP) Plan work is in progress by conducting baseline microbial sampling on all ground-tested plants. Early harvests of mizuna and tomato showed no difference in bacterial or fungal counts between light treatments or fertilizer. Mizuna has generally higher counts than lettuce but is similar to Chinese cabbage and counts are consistent between experiments (Fig. 5).

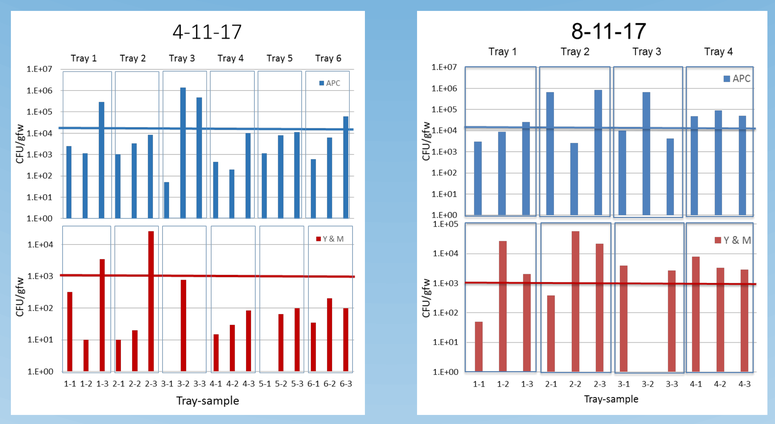

Fig. 5 Aerobic plate counts (APC) as colony forming units per g fresh weight for yeast and mold (Y+M) on individual mizuna plants sampled from experiments in controlled environment chambers under ISS-like conditions. 4-11-17 plants were taken from 6 fertilizer conditions, while 8-11-17 plants were taken from 4 light treatments. Dates indicate day of harvest. Horizontal lines indicate standards for non-thermostabilized foods, the closest approximate standards.

Behavioral Health

Characterizing the human response to the plant system in space will inform food systems and mission planners. The following measures will be taken:

- Profile of Mood States Short Form (**POMS-SF**) is a 5 min survey of how a crewmember feels at that point in time. 37 words describing feelings will be rated on a 5-point scale from *Not at all* to *Extremely*.
  - This approach has been extensively validated in research with both clinical and healthy populations.
- The Veggie Questionnaire (**VQ**) includes specific items that vary between preflight, inflight, and postflight and provide statements that describe individual's experiences with growing plants and vegetables. Crew will use the rating scale below each statement to indicate how accurately the statement describes them. Each survey contains approx. 15-20 questions and should take 5 min.
- One-time, preflight administration of the International Personality Item Pool (**IPIP-120**), which describes 120 behaviors and asks participant to rate how closely the behavior describes them, on a 5-point scale (from *Disagree Strongly* to *Strongly Agree*). Twenty preflight demographics questions will also be asked. Combined these should take 30 min.

Progress Toward Flight and Work Remaining

Human Subjects

- IRB approved, modification in work
- Informed Consent Briefings and subject enrollment begun
- Organoleptic tests at Johnson Space Center pending

Plant Flight Definition Testing

- Mizuna light ground tests complete; analysis underway (e.g., Fig. 6 – Few differences in elemental content in response to light treatments)

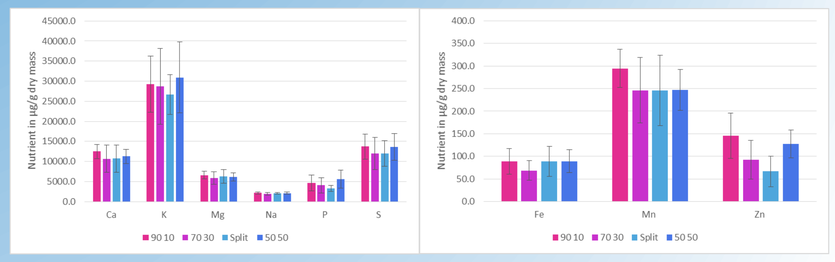

Fig. 6 Elemental data from mizuna ground tests. Averages ± SDs for n=18 plants.

- Mizuna cut-and-come-again growth test completed with chemistry in progress
- Tomato light ground tests in progress
- Tomato fertilizer ground tests in progress
- Data compilation in progress

Flight Preparation

- Flight growth hardware finalized and delivered
- On Board Training Videos under development
- Procedures under development
- Mizuna seed sanitization finalized; tomato in work
- Experiment Document VEG-04/05(ISSMP) and Experiment Requirements Document-VEG-04(SLPS) base lined
- VEG-04 Science Verification Test -11/29/17 to 1/23/18

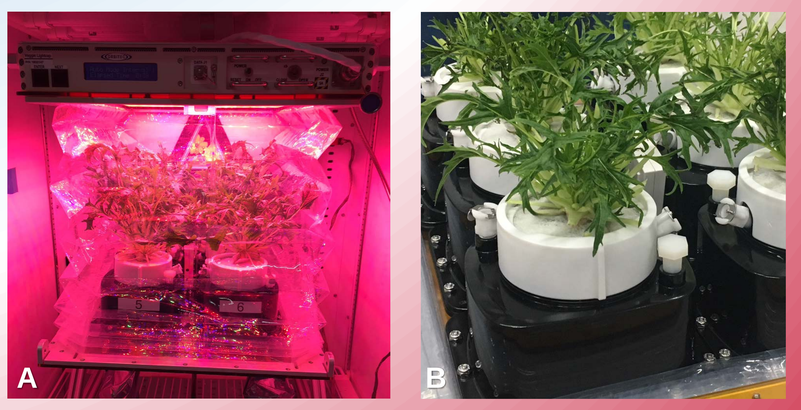

Fig. 7 A. Mizuna plants growing in Veggie in the PONDS hardware during the VEG-04 SVT. **B.** Close up of PONDS units after 1st cut-and-come-again harvest.

Acknowledgements

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