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Failure Testing: Analyzing Water Stress in Potential Space Crops Using a Smartphone Connectable Thermal Camera Technology

Giselle C.D. Gomez* and Brianna I. Esplugas

BioTECH @ Richmond Heights 9-12, 15020 Southwest 102nd Ave., Miami, FL 33176

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Scientists are currently investigating space crops to be grown for long term space flight while also optimizing growing conditions to ensure survivability. Human error, equipment failure, and limited time for astronauts to monitor the plants may lead to devastating crop failures with no additional payload arriving from Earth. The objective of this study is to simulate and analyze the impact of water stress on plants grown in space that may result from equipment failure and human error on long term space missions. *Brassica rapa* var. *japonica* (mizuna) and *Brassica rapa* var. *chinensis* ('Extra Dwarf' bok choy), two crops considered for space flight, were watered according to a predetermined schedule. A smartphone compatible thermal camera was used to document the different stages of water stress throughout the experiment. Although bok choy appeared, both visually and through infrared, physically more resistant to water stress, mizuna recovered almost completely when rehydrated and yielded a higher edible biomass. Reducing the watering from every two to every three days did not show any negative effect on biomass production. Dry matter of mizuna even increased. A watering schedule of every four days indicated a biomatter reduction. Although mizuna seemed to be visually more affected, it should still be considered the better choice due to its ability to recover easily from water stress.

Planning for long term space missions the sustainable production of fresh produce is one of the priorities. Keeping plants well hydrated and avoiding wilting through water stress is one of the challenges. In 2014 the first crop of lettuce (*Lactuca sativa*) was grown on the International Space Station (ISS) under microgravity using a system called "Veggie" (Massa et al., 2017). Plants are grown in plant pillows filled with a calcined clay and anchored to the base of the grow unit. Microgravity majorly dictates how the plants are maintained and how how they are affected by the environment on the ISS (Massa et al., 2013). Watering is one of the biggest challenges in microgravity due to its physical behavior. Water covers and clings to surfaces in a process called wetting. Wetting has a suffocating effect on plant leaves and roots when the water completely envelops the surface and hinders transpiration and water uptake processes. In the "Veggie" system, plants are watered using a manual process of injecting water into the pillows and a wicking system moves the water into the plants (Massa et al., 2017). Challenges for successful crop growth include limited space and resources in addition to limited available time for the astronauts to maintain plants. In this experiment, sustainability is targeted and challenged using pre-set manual watering cycles to test the recovery potential of mizuna and 'Extra Dwarf' bok choy. In order to observe how plants react to stress, thermal camera technology is applied to visually process the plants' responses before each watering. (Li et al., 2014).

Materials and Methods

Two Growing Beyond Earth (GBE) growth units were used, divided by plant trays into four separate units with felt (Beckett UL612 Pond underlayment, Beckett, Irving, TX) for wicking. The specimens were planted in peat moss (Sun Gro Horticulture, Vancouver, Canada) and turface (Turface Athletics (MVP), Buffalo Grove, IL) in a 1:1 (by volume) mix with a 7.5 g/L controlled release polymer fertilizer (18–6–8, type 70, Florikan ESA LLC, Sarasota, Florida) and exposed to a 12-h photoperiod.

Plants were randomized per tray and positioned accordingly. The control group, Treatment A, was watered every second day, Treatment B every third, and Treatment C every fourth day. Treatment D was also watered every second day but with half of the amount of water as Treatment A. Through the germination and early seedling period, 500 mL (Treatment D 250 mL) water was provided. This was increased to 1000 mL (Treatment D 500 mL) as the plants grew. To record the plants' internal temperature, indicating stress rate by dehydration, a smartphone connectable camera (Seek Thermal Inc., Santa Barbara, CA) was used. For the thermal indices, the leaves of the specimen were covered

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*Corresponding author email: mlitzinger@fairchildgarden.org; cc: ggomez2000@live.com

in petroleum jelly as a dry reference and sprayed with water as a wet reference (Leinonen and Jones, 2004; Jones et al., 2009) before recording the temperature of the test plants. Plants were harvested 40 days after planting (DAP) and fresh and dry weight collected. For dry weight, specimens were dried at 72°C for at least 3 days.

Results and Discussion

Although a trend was observed among the treatments (n = 4) no significant differences were recorded (Tables 1 & 2). The most favourable watering cycle seems to be Treatment B. The thermal camera allowed for the observation of internal temperatures of plants, which shows stress level during times of drought. Although mizuna wilted easily when there was a shortage of water, it recovered quickly, once the turgor increased again after watering. According to observations with the thermal camera, plants with an internal temperature of 16 to 18 °C indicate adequate water retention and a stable internal system; the plant is at homeostasis (Fig. 1). When observing Treatment C, it was apparent through observation that the continuous wilting took a toll on the plant's recovery and affected yield of both crops. A second trial was planned with an increased sample size of n = 16 and using only Treatment A, B, and C but was not successful due to equipment failure in the laboratory and air temperatures of 32 °C for a period of 8 days. The young seedlings began flowering due to heat stress which compromised the data. For the purpose of improved sustainability in the ISS and more edible plants, Treatment B (every 3 days) or Treatment D (every other day but 1/2 of A) is recommended for 'Extra Dwarf' bok choy and mizuna.

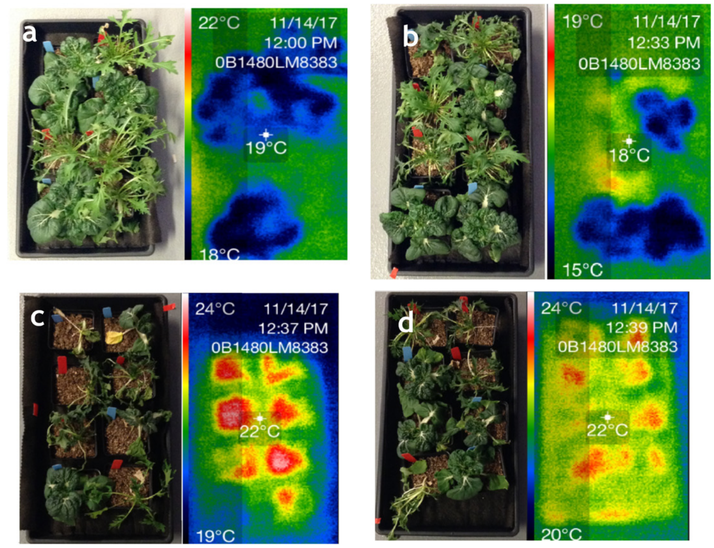

Fig. 1. Images of plants and thermal camera images for week 1. (**a**) Treatment A, watered every 2 days with 500 or 1000 mL. (**b**) Treatment B, watered every 3 days with 500 or 1000 mL. (**c**) Treatment C, watered every 4 days with 500 or 1000 mL. (**d**) Treatment D, watered every 2 days with 50% of water from A, 250 or 500 mL.

Table 1. Edible fresh weight of mizuna and 'Extra Dwarf' bok choy.

Variety	A[z] (g/plant)	B[y] (g/plant)	C[x] (g/plant)	D[w] (g/plant)
Mizuna	36.3 ± 5.5	71.9 ± 10.4	40.8 ± 15.6	34.6±6.5
Extra Dwarf bok choy	50.3 ± 14.5	57.0 ± 32.1	32.0 ± 20.3	47.6±5.1

[z]Treatment A: watered every two days with 500 or 1000 mL.
[y]Treatment B: watered every three days with 500 or 1000 mL.
[x]Treatment C: watered every four days with 500 or 1000 mL.
[w]Treatment D: watered every two days, 50% water of A with 250 or 500 mL.

Table 2. Dry weight of mizuna and 'Extra Dwarf' bok choy

Variety	A[z] (g/plant)	B[y] (g/plant)	C[x] (g/plant)	D[w] (g/plant)
Mizuna	2.8 ± 0.7	3.60 ± 2.2	2.35 ± 1.5	3.14 ± 0.3
Extra Dwarf bok choy	3.6 ± 0.9	3.74 ± 2.1	3.22 ± 1.4	3.18 ± 1.0

[z]Treatment A: watered every two days with 500 or 1000 mL.
[y]Treatment B: watered every three days with 500 or 1000 mL.
[x]Treatment C: watered every four days with 500 or 1000 mL.
[w]Treatment D: watered every two days with 250 or 500 mL., 50% of A.

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