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Space Horticulture Meets Citizen Science: First Results from Three Years of Data Pooling to Find the Perfect Space Crop

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As the National Aeronautics and Space Administration looks toward a long term human presence beyond Earth's orbit, there are specific science, technology, engineering, and math (STEM) challenges related to food production in space. Fairchild Tropical Botanic Garden is specifically working on identifying suitable, hardy, and nutritious crops to be grown aboard spacecraft.

Established in 2015 as a partnership between Fairchild Tropical Botanic Garden (Fairchild) and the National Aeronautics and Space Administration (NASA) Exploration Research and Technology Programs, Fairchild's Growing Beyond Earth program has been initiated in 120 South Florida, Ohio, and Puerto Rico schools. Fairchild has enlisted a network of thousands of middle and high school students who participate in the Fairchild Challenge environmental education outreach program. Fairchild provides schools with hardware designed to be analogous to the International Space Station (ISS) as well as specific research protocols created in collaboration with the researchers at Kennedy Space Center (KSC), consumable materials, and cultivars chosen based on their ability to grow in the conditions on the ISS. Students run simultaneous plant experiments in their classroom and all data are reported back to Fairchild and NASA through a shared database.

In the first three years, 106 species and cultivars, including leafy vegetable and small fruiting crops, have been tested for their ability to produce high amounts of edible biomass under limited growing conditions. NASA is using these results to find promising candidates and harvesting procedures for further testing in space. Top performing cultivars were selected and a cut-and-come again harvest was performed on ISS after being tested in the classrooms.

Long term space flight and extraterrestrial settlements introduce new challenges for scientists and astronauts alike. A successful sustainable food supply in an enclosed system and the nutritional value of the food produced are important factors to keep the astronauts supplied with the vitamins and minerals needed for a healthy diet (Smith and Zwart 2008, Massa et al. 2015, Massa, Simpson et. al. 2013). To evaluate the hundreds of potential suitable cultivars, thousands of middle and high school students in South Florida took on the task of growing and measuring crops in a large citizen science experiment, Growing Beyond Earth (GBE).

Plants on long-term space flight not only serve as food but also enhance the wellbeing and happiness of humans in a sterile non-color environment (Massa, Simpson et al., 2013, Ulrich and Parson 1992). Every plant cultivar is unique, with its own ideal growth conditions in terms of light, photoperiod, water, nutrients, and temperature during the different stages of growth. Not only microgravity, but also the cost of payload, available growth space and limited manpower on a spacecraft add to the challenges of growing plants for long term space flight.

Filtering through hundreds of potential crops that may fit these requirements, including robustness and low maintenance, high biomass production, and an ideal balance of nutrients and vitamins, is a task requiring extensive manpower. It also gives students the unique opportunity to conduct the baseline research for scientists in their classrooms. The ability to share the collected data allows students to easily receive feedback from scientists via social media. It also empowers students and boosts their confidence in the field of science.

Materials and Methods

GBE has been integrated into the Fairchild Challenge (FC), an annual multidisciplinary competition running successfully for 16 years in Miami-Dade County, FL and engages more than 125,000 K–12 students annually. The GBE portion of the FC is heading into its fourth year, using a workforce of more than 5000 middle and high school students to filter through potential crops for space flight. At the beginning of each school year, teachers are invited to participate in a mandatory professional

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development workshop for all schools participating in the GBE project. During this one-day workshop, NASA scientists provide recent updates about their research to the participating teachers and answer questions about the project. Protocols, developed by Fairchild and KSC scientists, are distributed and discussed in detail with the teachers. This enables them to teach the concept in their classroom and to standardize and facilitate data input. In addition to research on different cultivars, other variables may be addressed, such as photoperiod and fertilizer application. After the trials, schools are required to submit an entry to the FC competition and their research findings are also shared with NASA scientists.

Hardware. The standard provided hardware to each classroom includes a 60 cm × 58 cm × 135 cm shelving unit (Uline, Pleasant Prairie, WI) and a growth chamber. For the growth chamber a drip tray (Funnel King, Global Industrial, Port Washington, NY) serves as a water reservoir and a PVC sheet (Rug Gripper TrafficMaster, Shaw Industries, Inc, Dalton, GA) and polypropylene/polyethylene felt (Beckett UL612 Pond underlayment, Beckett, Irving, TX) are used as wicking surfaces. The sides of the growth chamber are constructed with translucent corrugated plastic panels (Blick Art Materials, Galesburg, IL) cut to 35 cm × 50 cm and 40 cm × 50 cm inch sheets (placed opposite) and 40 cm self-adhesive corner protectors (Koffler Sales, LLC, Lake Zurich, IL). The growth chamber is covered with a 54 cm × 54 cm transparent corrugated PVC sheet (Palruf, Palram Industries Ltd./Palram Americas Ltd, Kutztown, PA). A thermometer/hygrometer (Iap Sales, St. Paul, MN) is attached to the inside of the growth chamber with velcro (Velcro USA Inc., Manchester, NH). Plants are grown in 500 mL (10 cm × 10 cm) plastic pots (Second Sun, Lebanon, PA), and in peat moss (Sun Gro Horticulture, Vancouver, Canada) and calcine clay (Turface Athletics (MVP), Buffalo Grove, IL) in a 1 peat moss: 1 clay (by volume) mix.

Depending on the planned research, different cultivars (Baker Creek Heirloom Seed Co, Mansfield MO, Johnny's Selected Seeds, Fairfield ME, Kitazawa Seed Co., Oakland CA, Park Seed, Hodges SC) and premeasured coordinating slow release N–P–K fertilizer, mainly 18–6–8 and 14–4–14 (Massa et.al, 2015) with different release times (Total Nutricote, Florikan ESA Corporation, Sarasota, FL) are included in the project kit. Seeds have undergone prior germination trials by interns during the summer to ensure success when the grow unit is placed in the classroom.

Data collection process. The research trials are a combination of 28–30 days for leafy greens (Massa, Newsham et al.), 60 days for a cut-and-come again harvest as well as for most herbs, and 90 days for fruiting crops. All seeds are randomized (random.org, Dublin, Ireland) and schools work with three or four crops per trial, also randomized. The students follow the weekly measurement and final harvest instructions of the respective protocol. For leafy greens this includes size and edible fresh mass, for fruiting crops, size and the number of fruit harvested. Further statistical analyses of all the data pooling is done at Fairchild.

All collected data are recorded in an online database (google.com, Google LLC, Mountain View, CA) and shared with scientists of the "Veggie" team at KSC. As an additional communication tool schools are encouraged to post pictures of scientific relevance on social media (twitter.com, Twitter Inc., San Francisco, CA). The school's progress is monitored and mentored by Fairchild staff.

Additional opportunities. Fairchild offers a six-week summer internship through the FC for students who would like to intensify their plant research. The interns take the results from the previous school year and further the study by modifying the growing conditions. A second high school student group, 11th grade students from BioTECH@Richmond Heights, Miami, FL, are conducting year-long research with GBE plants in their research class with the goal of publishing a scientific paper or presenting their work at a conference. Both student groups have the opportunity to interact with scientists from KSC on a specially designed field trip.

Results and Discussion

Pre-pilot and feasibility study 2015–16. High school and middle school students tested 54 cultivars in 30 day trials with 'Outrageous' Red Romaine Lettuce (*Lactuca sativa*) as a control. Based on results 16 of the tested cultivars produced more than 30 g of edible biomass/plant, 12 species and/or cultivars produced more than 20 g of edible biomass/plant in the 30-day trials represented by mostly Brassicaceae cultivars. The classroom observations through social media showed that measurements were not necessarily collected correctly, so tested crops were further analyzed using student-measured plant height. Most of the crops did not follow the normal distribution but showed a wide range of results, indicating that some crops produced a good growth rate even under the diverse and sometimes uncontrollable conditions of the classroom.

In the second half of the school year, eight cultivars were selected from the first trials and tested by high school students in a 60-day cut-and-come-again harvest, again with 'Outrageous' red romaine lettuce (*Lactuca sativa* subsp.) as a control; 'Bright Lights' chard (*Beta vulgaris* subsp.); 'Red Kitten' spinach (*Spinacia oleracea* subsp.); shungiku (*Glebionis coronaria*); komatsuna (*Brassica rapa* var. *perviridis*) × tatsoi (*Brassica rapa* var. *Narinosa*) *misome* (*Brassica campestris var. narinosa*); sylvetta (*Diplotaxis tenuifolia*); molokhia (*Corchorus olitorius*); and sorrel (*Rumex acetosa*) as experimental plants.

Plants yielded more than twice as much fresh mass than in a 30-day trial providing fresh produce once a week starting after 20 days. Misome, a new Japanese all-season green, had the highest yield and fared the best under the wide array of classroom conditions.

Pilot year 2016–17. High school and middle school students tested additional cultivars, including fruiting plants, which increased the number of tested plant selections to 94.

High schools received tomato and pepper seeds for a 90-day trial with 'Red Robin' Tomato (*Lycopersicon esculentum*) as a control. Different fertilizer rates and blends were administered. Not enough data were available for statistical analyses, but it was observed that plants treated with additional calcium nitrate and potash produced higher yields.

Middle school students tested a range of herbs and leafy greens in a 60-day trial. Based on the growth results of these trials, KSC scientists selected the following top ten for further study: 'Dragoon' lettuce (*Lactuca sativa*); 'Extra Dwarf' pak choi (*Brassica rapa chinensis* group); 'Petite Snap-Green Peas', which has unique leaflets and edible shoots and blossoms (P*isum sativum*) times dill (*Anethum graveolens*); ice plant (*Mesembryanthemum crystallinum*); both 'Large Leaf Tong Ho' and 'Garland Round Leaf' shungiku (or garland) chrysanthemum (*Glebionis coronaria*); borage (*Borago officinalis*); 'Cressida' "curly cress" or "peppergrass" (*Lepidium sativum*); and 'Pluto' basil (*Ocimum minimum*).

Year 1 2017–18. High school and middle school students tested a variation of leafy Asian greens for their biomass production which increased the number of tested cultivars to 106. Final results are pending. High school students were asked to design their own experiments based on the results of their first trial and presented their research at the FC Student Research Symposium in April. Scientists from NASA were invited to evaluate the student posters and discuss the results with the students.

Scientists from KSC followed the students' efforts of data collection and provided feedback via social media. Translating the results of the student research to NASA, astronauts on ISS are now using a cut and come again harvest to increase the harvesting period of the crops. The first three crops planted on the ISS were monocultures, while the following crops included multiple cropping based on the results of student research. Further data analysis done by KSC scientists provided a short list of promising new "Veggie" candidates, two of which will be planted on the next crop cycle on ISS, 'Dragoon' lettuce (*Lactuca sativa*) and 'Extra Dwarf' pak choi (*Brassica rapa chinensis* group).

Conclusion

In its first years, GBE has produced applicable results supporting NASA's plant research. The GBE project is a flexible program that has evolved over the past few years from simple data collection and data pooling by students to college grade scientific poster presentations. A firm program structure, easy to follow protocol and simple data entry are crucial for reliable data collection.

Scientists from the "Veggie" team used the collected data to confirm harvesting procedures and evaluate trends while assessing the next generation of edible crops to be flown in space. Further testing will be conducted in the next crop cycle in school.

The hardware used by the students is continuously being improved and adapted. The requests for nationwide project expansion will make it necessary to rethink the basic concept and design a more flexible grow unit that can be easily distributed as well as establish new remote training methods.

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