"Space Pomology": Dwarf Plums for Fresh Food Production

LaShelle Spencer[1], Thomas Graham[2], Gary Stutte[1], Gioia Massa[1], Matthew Mickens[1], Raymond Wheeler[1]

[1] Kennedy Space Center, Florida and [2] University of Guelph, Ontario

ABSTRACT

Recently, USDA ARS researchers genetically modified plums for rapid breeding work and noticed the plants could flower and develop fruit rapidly on relatively small plants. We have tested several of these genetically modified (GM) plums in plant chambers to assess their potential as a space crop. We have been able to clone these genetic lines using "cuttings" that are rooted using growth regulating compounds. Results showed that the GM plums indeed flower and fruit on small plants in controlled environments similar to what might be used in space, but they require cross-pollination with pollen from a standard plum. Analysis of stomatal conductance and leaf transpiration showed that water use went up in the light period, as expected, and but that GM types typically showed higher conductance than a standard plum. Analysis of tissue showed that fruit could be a good source of potassium and phenolic compounds, which could be beneficial as a bone loss countermeasure (Smith et al., 2014). These findings are all promising for using dwarf GM plums as a supplemental food for space, but further horticultural testing is needed before they are ready.

BACKGROUND

Fresh fruits grown in space could provide a valuable supplement to stowed foods. But most fruits used in the human diet are grown on trees, and trees have typically been dismissed from consideration as space crops due their size and dormancy (cold period) requirements. Researchers at the USDA have recently developed a rapid crop breeding technology (FasTrack) where plum (*Prunus domestica)* was transformed with the FT1 plant gene using a 35S promoter (35S::PtFT1), which reduces the juvenile phase of the plums from 3-7 years to < 1-year (Srinivasan et al., 2012). This modification was accompanied by an elimination of dormancy requirements and a vine or dwarf/bush growth habit. This development provided an opportunity to study a tree fruit compatible with the mass, volume, and time constraints for spaceflight crop production (Fig. 1).

Figure 1. Young cutting of PfFT1 plum with a flower (left), and Matt Mickens (KSC) Pollinating plum flowers (right).

Plums are known to be a high source of vitamin K, with a phytochemical compliment that has been strongly linked to the prevention of bone density loss and disease prevention in both mouse and human models (Smith et al., 2014). This could make plums a particularly valuable supplemental food for spaceflight.

METHODS AND MATERIALS

Goal 1 of this phase of the project was to evaluate stomatal conductance / leaf transpiration rates of four GM lines ('NASA-5', 'NASA-6,' 'NASA-10' and 'NASA-11') at ambient and elevated CO_2 using a controlled environment growth chamber. Two repetitions of 400 ppm CO_2 and 1500 ppm CO_2 were completed. Stomatal conductance measurements were taken with a Decagon SC-1 Leaf Porometer (Decagon, Pullman, WA) across an entire diurnal cycle, i.e., 06:00, 08:00, 11:00, 15:00, 19:00, 22:00, 00:00 and 03:00.

Goal 2 was to evaluate flowering and fruiting of the different PtFT1 plum genotypes. Flowers were hand pollinated (n=13) with standard plum pollen provided by the USDA / ARS (Kearneysville, WV) and were tagged to track time to harvest. Fruit that developed from these and prior trials were subsequently analyzed for phytonutrients and elemental composition

Goal 3 was to determine an adequate clonal propagation technique for producing plant material for launch to ISS.

RESULTS AND DISCUSSION

Stomatal Conductance

Periodic stomatal conductance measurements across the day (light / dark) cycle for the different GM lines and standard plums showed a typical diurnal cycle of lower conductance at night (i.e., the stomata tend to partially close) and higher conductance in the light (Wheeler et al., 1999). The circadian rhythm was somewhat damped at the elevated (1500 ppm CO_2) for both the GM PtFT lines and the standard plums, especially for the second set of measurements (Rep 2) (Fig. 2). The data also show that the nocturnal conductance rates for the GMO lines were higher than those for the standard plums, suggesting the GM lines use more water during the dark period (Fig. 2). In addition, the elevated CO_2 did not appear to reduce conductance for the GM lines, as might be expected for a C_3 plant like plum (Wheeler et al., 1999), especially for the Rep 2 measurements. This suggests that the GM plum lines might be heavier water users than the standard plums.

Flowering and Fruiting

The average time from pollination, to first sighting of fruit was about 7 days. Time from first fruit sighting to first signs of ripening (i.e., appearance of purple color in the fruit skin) was ~50 days. It typically tood an additional 11 days for fruit to fully ripen, adding to a total time of about 68 days to go from pollination to mature fruit. Fruit that developed from these flowers often had two or more stones (seeds) and the flesh was smooth and very juicy (Fig 3.).

Fruit Phytonutrient Analysis

Analysis included: 1) Overall anti-oxidant potential, using the oxygen radical absorbance capacity (ORAC) assay as a general indicator of bioactive components, 2) anthocyanins as countermeasure against oxidative stresses, 3) lutein and zeaxanthin as bioactive countermeasures for vision issues associated with long duration exposure to microgravity, and 4) elemental composition. Tissue were freeze dried prior to all measurements and data are expressed on a dry weight basis.

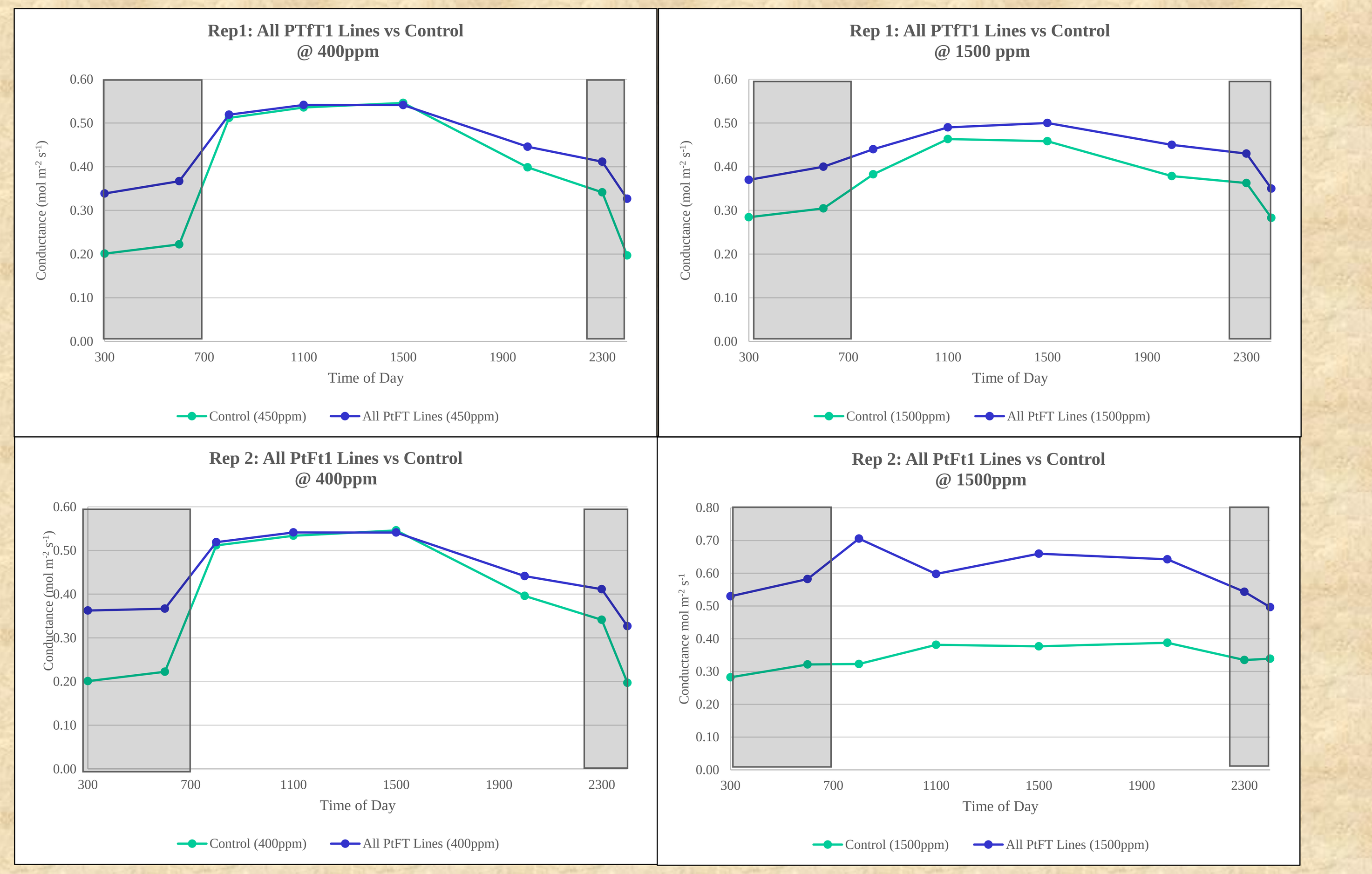

Figure 2. Rep 1 & 2 diurnal porometry measurements taken from young plum leaves at 400 ppm and 1500 ppm CO_2. Shaded areas denote nighttime (dark periods).

Figure 3. Dwarf GM plum fruit morphology and size (note double fruit in middle), and flesh of a whole pealed fruit and slices of fruit (right).

Line	N=	mg/g DW				mg/g DW		µmol TE/g/DW	µg/mg DW	mg/g DW
		Ca	K	Mg	Zn	Lutein	Zeaxanthin	ORAC	Anthocyanin	Total Phenolics
Nasa-5	10	3.28	17.25	1.7	0.12	0.2	BDL	257.1	0.3	23
Nasa-11	21	0.81	19.34	0.7	0.09	0.1	BDL	121.6	0.3	15.5

Table 1. Tissue analysis of plum fruit. Data represents means of N samples.
BDL= Below Detection Limit; DW = Dry Weight.

RECOMMENDATIONS

It is possible to clonally propagate and harvest fruit from transformed PtFT1 plums in a period as short as 9 months, with plants only reaching about 40-50 cm height. Based on ease of rooting, precocity of flowering, ease of training, and environmental resilience, we recommend PtFT1 genotype NASA-11 for further testing. Testing should focus on optimizing water use and nutrient managments. Evaluation of different pruning practices for maintaining plant size and optimizing fruit production are also needed. Because these GM plants are largely self-incompatible for pollination, further work to develop self fertile or possibly parthenocarpic lines would be beneficial for long duration space missions.

REFERNCES

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