Legume Crop Testing for Space

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Long-duration missions beyond low-Earth orbit will encounter challenges in maintaining adequate nutrition and crew acceptability in the food system. *In situ* production of fresh produce can supplement nutrient deficiencies in the prepackaged diet. Currently, there are a relatively small number of crops that can be reliably grown for space crop production efforts. Recent challenges with Veggie plant growth technical demonstrations, such as interveinal chlorosis and necrosis of Tokyo Bekana Chinese cabbage when grown under elevated CO_2 (~3000 ppm) and narrow-band LED lighting, have highlighted the necessity to conduct rigorous ISS-relevant crop screening on the ground. Additionally, crops should be selected to address specific nutritional deficits, as identified by NASA's Human Research Program, with an emphasis on having a diversity of crops to meet nutritional requirements and crew acceptability. To achieve this, the concept of Crop Readiness Level (CRL) has been developed to gauge readiness of crops for spaceflight applications. CRL determination includes assessing environmental compatibility, food safety considerations, relevant nutritional analysis, and sensory analysis. Recent testing at Kennedy Space Center has focused on advancing the CRL of a variety of legumes. Twenty-four varieties of peas (*Pisum sativum)* and beans *(Phaseolus vulgaris)* were grown under 300 µmol m^{-2} s^{-1} PPFD from LED lights, 3000 ppm CO_2, and 23 °C to simulate an ISS environment. Crops were harvested and size and yield were assessed. Then, baseline nutritional analysis (Vitamins B1, C, K; elemental analysis; proximate analysis) and sensory evaluation were performed on eight down-selected varieties. These baseline tests will help in selecting candidate crops for future missions and assessing crop production hardware and changes in environmental conditions on future crop performance and nutritional quality.

Nomenclature

LED	=	Light Emitting Diode
CRL	=	Crop Readiness Level
PPFD	=	Photosynthetic Photon Flux Density
ISS	=	International Space Station
EC	=	Electrical Conductivity
DAP	=	Days after planting
APH	=	Advanced Plant Habitat

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RGB = Red Green Blue
FR = Far Red

I. Introduction

As we move toward long-duration, exploration class missions, the capability to grow nutritious, palatable food for crew consumption during spaceflight becomes increasingly important[1,2,3]. Critical nutrients have been proven to degrade over time in pre-packaged, thermo-stabilized meals, to the extent that they will not meet the shelf-life requirements of long-duration mission scenarios[4,5]. Supplementing these nutrients through pharmaceutical methods has not been recommended due to concerns with possible side effects, faster degradation of nutrients in supplement form, crew compliance, and lack of synergistic benefits associated with the natural combination of phytochemicals in whole-food delivery. Implementation of a pick-and-eat bioregenerative produce system in spaceflight has tremendous potential to supplement nutrition over time, while supporting crew psychosocial health through the introduction of fresh foods that increase the variety, texture, flavor, and color attributes of the food system[6]. To date, the testing of edible crops for spaceflight has been limited to largely leafy green species. A common approach to these studies is to simulate the types of environments that might occur in International Space Station (ISS), in plant chambers like Veggie, for example, under elevated CO_2, LED lighting, and typical ISS cabin temperatures and humidity. Regardless of the plant growth chambers used for the ISS and future vegetable production systems, growth volume and shoot/canopy height will be limited. For example, shoot height available for the Veggie and Advanced Plant Habitat (APH) growth chamber systems onboard the ISS are 47 cm and 45 cm, respectively.[7]

A next step for supplementing food crops for space might be the inclusion of small fruit or seed crops, such as tomato, pepper, or legumes. A legume is a plant in the Fabaceae family and include species such as clover, alfalfa, tamarind, peanuts, chickpeas, peas, soybeans, and beans. Legumes are most notable for the symbiotic relationship between the nitrogen fixing *Rhizobia* bacteria and their root nodules[8]. Many legumes are highly nutritious, as they are an excellent source of protein, fiber, B vitamins, iron, zinc, magnesium and phosphorous[9]. For this reason, they are being evaluated for biological performance, suitability, nutritional content, and acceptability under ISS-like environmental conditions. Legume crops like pole beans, bush beans, and peas are commonly grown in outdoor fields or greenhouses, but only limited testing has been conducted in completely controlled environments.[10,11] Cultivar selection will be very important, as some varieties are tall growing types that would not work well in space. Regardless of the size, fruiting crops must go through flowering and pollination/fertilization stages and could require longer growth cycles to reach harvesting age (e.g., 70-100 days). Despite this, peas have already had their time in space. In the period from March 2003 to April 2005, genetically marked peas were grown in the Russian LADA greenhouse. During these tests, they found that seed-to-seed growth and development was not that much different from ground control plants.[11,12]

For these studies, we wanted to 1) assess the morphology, yield, and viability of crops grown in mission relevant environmental conditions, 2) evaluate organoleptic acceptability, and 3) determine nutritional value of several legume cultivars. These findings can help us advance these new species and cultivars through a "Crop Readiness Level" (CRL) evaluation for eventual spaceflight applications.[13]

II. Materials and Methods

Legumes were grown in two environmental growth chambers (Percival PGW-48, Perry, Iowa) located in the Space Station Processing Facility at NASA Kennedy Space Center, Florida (located at sea level with atmospheric pressure of ~101 kPa). The chamber air temperature, relative humidity (RH), and CO_2 setpoints were maintained at 23 °C, 50%, and 3000 ppm, respectively, for all tests. These set points were chosen to simulate an environment similar to that of the ISS cabin air.

Seeds were sown in square plastic pots (9 cm tall, 10.2 cm wide) containing 70% professional growing mix (Sun Gro, Agawam, MA) and 30% arcillite (Turface MVP, PROFILE Products LLC; Buffalo Grove, IL). During cultivar screening tests, four plants of each cultivar were randomly placed between the two chambers to minimize chamber effects. During the final down select test, where fruits/pods were to be utilized for nutritional analysis and organoleptic tests, similar sized cultivars were grown in a group. This approach was not optimal for offsetting potential position effects, but was the best approach to minimize shading of shorter cultivars by taller cultivars, which could potentially reduce yields. In each pot, four seeds were sown just below the surface of moistened media. Pots were automatically irrigated to excess several times daily with Peter's 13-2-13 (Everris, Geldermalsen, The Netherlands) nutrient solution, which was maintained at pH 5.8-6.5 and 750 µS cm^{-1} electrical conductivity (EC). Trays were covered with transparent plastic for the first seven days to promote germination. Once true leaves emerged, seedlings were thinned to one per pot and the EC was increased to 1200 µS cm^{-1} for the remaining growth period.

Lighting was provided by Heliospectra LED grow lights (RX30, Göteborg, Sweden). The photosynthetic photon flux density (PPFD) target was 300 µmol m^{-2} s^{-1}, averaged over the entire canopy, with a 16-h (16 h light/8 h dark) photoperiod. Spectral quality consisted of 23% blue (400-500 nm), 27% green (500-600 nm), and 50% red (600-700 nm), using a combination of 450 nm, white (5700 K), 630 nm, and 660 nm LEDs.

III. Crop Assessments

General appearance was monitored qualitatively throughout the experiment, and weekly photos of the crops were taken. A list of the pea (*Pisum sativum*) and bean (*Phaseolus vulgaris*) species and cultivars is shown in Table 5.

A. Harvest Metrics

Once fruit/pods became ripe, they were harvested at approximately weekly intervals (3-5 harvests, depending on cultivar production), and plant growth measurements were performed. Harvest measurements included individual fruit/pod fresh and dry weight, fruit/pod diameter and length (stem to blossom), individual fruit/pod weight, and weight of the total amount of fruit from each plant. A final harvest, shoot height, and shoot fresh and dry weight were also collected.

B. Sensory Analysis

Sensory evaluation was conducted at the Space Food Systems Laboratory sensory evaluation center using the untrained sensory volunteers at Johnson Space Center ($n \geq 25$). Each sample was rated on appearance, color, aroma, flavor, texture, and overall acceptability on a 9-point hedonic scale, where 1 corresponds to "dislike extremely" and 9 corresponds to "like extremely." Panelists also evaluated "Just about right" (JAR) criteria for crunchiness, juiciness, freshness, sweetness, and bitterness.[14]

C. Nutritional Analysis

Ripe fruits were harvested and shipped to a commercial laboratory (Eurofins Nutritional Analysis Center, Des Moines, IA), where they were analyzed for proximate composition (ash, calories, carbohydrates, fat, moisture, protein), elemental content (calcium, iron, magnesium, phosphorous, potassium), and vitamin content (B1, C, K).

IV. Results

D. Harvest Metrics

Twenty-four cultivars of pea and bean were tested, and total shoot biomass yields, average plant height, average fruit/pod yield per plant, and number of harvests, amongst other parameters, were collected. Using foliage height, yield, and general plant appearance as a guildine, eight good performers were identified. These were 'Yellow Snap 485-2' (snap pea), 'ES Thick Pod 404-51-2' (snap pea), 'ES Thick Pod 404-51-2-1' (snap pea), 'Royal Snap' (snap pea), 'Velour Purple' (snap pea), 'Antigua' (bean), 'Tom Thumb' (pea), and '4921' (bean).

Total shoot fresh biomass is a good initial indicator for cultivar performance, particularly in terms of potential fruit production. The top four highest producing cultivars in descending shoot fresh weight, were 'Yellow Snap 485-2' (448.41 g), 'Early Snap 91E' (428.09 g), 'Blue Bantam Dwarf' (373.65 g), and Honey Snap (yellow) (349.4 g) (**Figure 1**). Of these highest producing cultivars, 'Yellow Snap 485-2' had already been identified as a good performer, as it had the highest fruit/pod fresh weight production occurring over four harvests from 50-79 days after planting (DAP). Even though 'Honey Snap (yellow)' was the fourth highest producing cultivar for shoot fresh biomass, it had late pod set, allowing for only three harvests from 64-88 DAP.

Plant height is another important consideration for cultivar selection when plant growing area is a limiting factor. More compact plants allow for the growing area to be planted with more high producing plants, to optimize the total production inlimited growing areas and volumes of space habitats. The five most compact cultivars included 'Tom Thumb' (17.25 ± 7.79 cm), '4921' (22.20 ± 3.00 cm), 'Velour Purple' (22.63 ± 1.24 cm), 'Earligreen' (23.75 ± 4.02 cm), and 'Antigua' (38.25 ± 4.94 cm) (**Figure 2**). Of these, 'Tom Thumb', '4921', 'Velour Purple', and 'Antigua' were identified as good performers in terms of yield. The top five tallest plants included 'Early Snap Pea 430-1-4-1-2' (77.75 ± 4.97 cm), 'Little Snap Pea Crunch' (77.75 ± 4.60 cm), 'Feisty Pea' (75.05 ± 2.68 cm), 'Early Snap Pea Thick Pod/ 404-35-1-2-1' (74.75 ± 2.94 cm), and 'Royal Snow (purple snow)/99-7-1-1' (74.63 ± 4.82 cm). Tall growth is considered an undesirable trait for space crops.

Fruit/pod fresh weight yield is a prime consideration for cultivar selection. The top five highest average yield per plant included ‘Multi Leaf (snow pea)/220-1-2’ (39.70 ± 24.45 g), ‘Blue Bantam Dwarf’ (37.37 ± 24.13 g), ‘Acacia Leaf (snow pea) 220-1-2’ (36.49 ± 19.92 g), ‘Very Early Snap Pea/351-6-1’ (36.43 ± 25.04 g), and ‘Honey Snap (yellow)’ (34.94 ± 26.85 g) (**Figure 3**). Although these cultivars produced high yields, none were selected as high performing due to their large size and/or late pod set, amongst other unsatisfactory qualities. The five lowest average yielding cultivars included ‘Earligreen’ (8.46 ± 3.66 g), ‘Tom Thumb’ (12.42 ± 6.11 g), ‘PLS 0122’ (13.94 ± 5.38 g), ‘PLS 0120’ (14.15 ± 5.98 g), and ‘Early Snap Pea Dark Green/412-1-1’ (20.61 ± 18.01 g) (**Figure 3**). Even though the cultivar ‘Tom Thumb’ was included in the lowest average yield per plant, it did produce very early and consistent harvests throughout the grow out, which may outweigh this unsatisfactory quality of this cultivar.

Using qualitative plant health, yield, and overall plant height as a selection critera, four short varieties (‘ES Thick Pod 404-51-2’, ES Thick Pod 404-51-2-1’, ‘Royal Snap’, and ‘Yellow Snap 485-2’) and four tall varieties (‘Velour Purple’, ‘Antigua’, ‘Tom Thumb’, and ‘4921’) were down-selected for further testing.

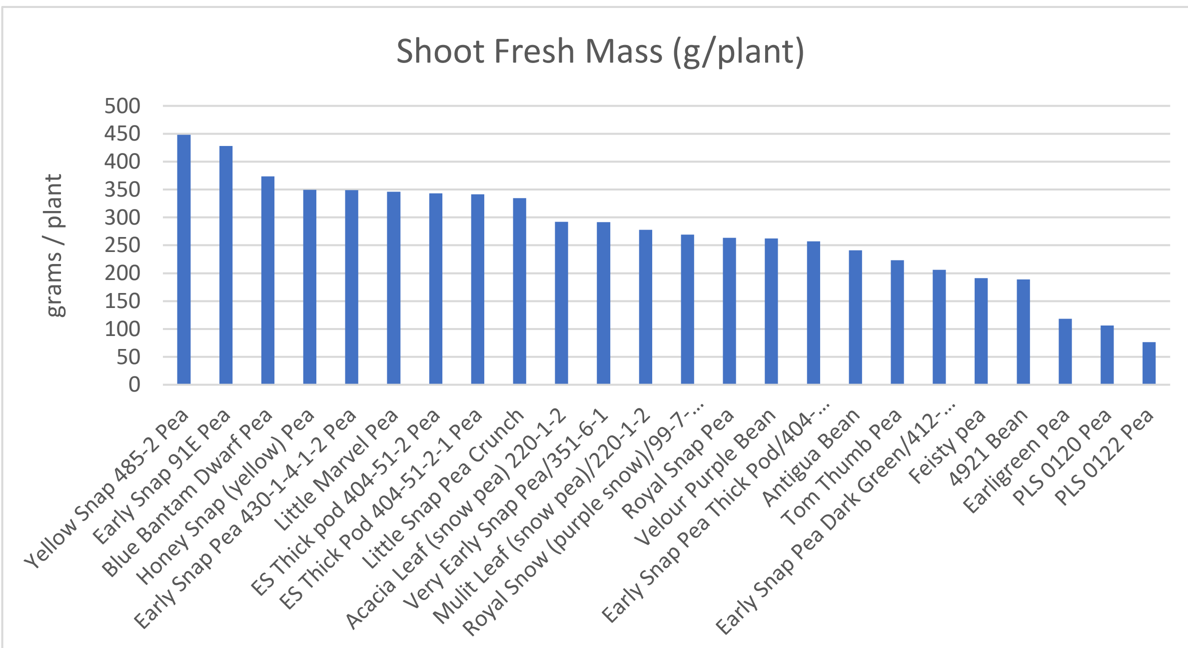

Figure 1. Total shoot fresh mass of legume cultivars grown in controlled environment.

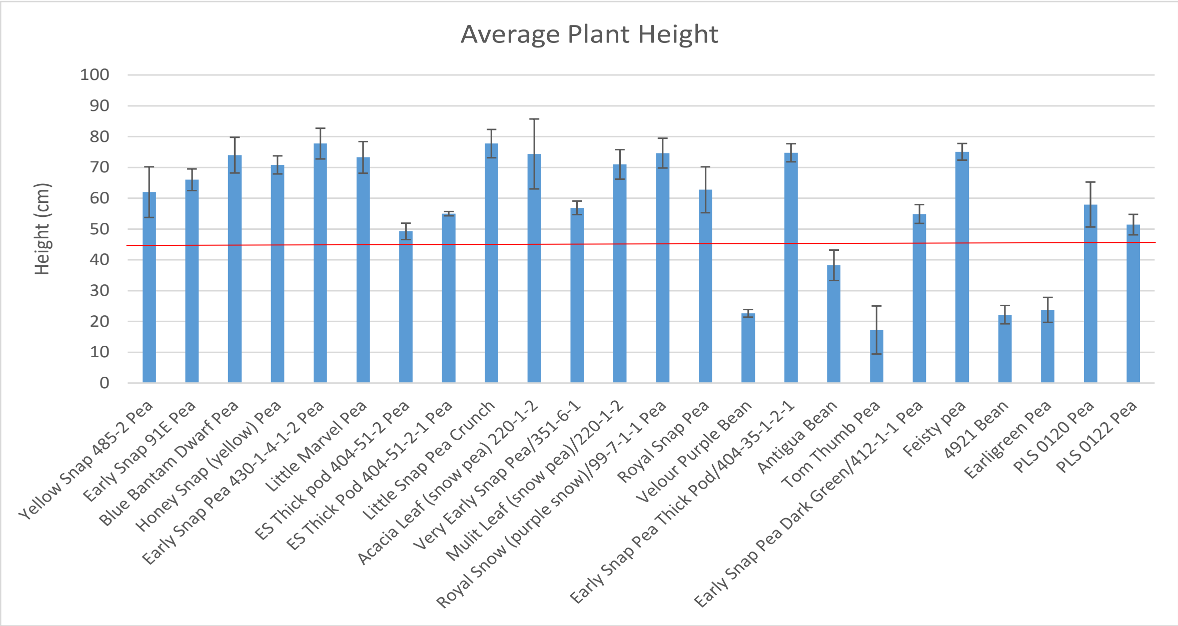

Figure 2. Average height of legume cultivars grown in controlled environment. Error bars are standard deviation (n=4). Line denotes approximate height available in APH and Veggie facilities.

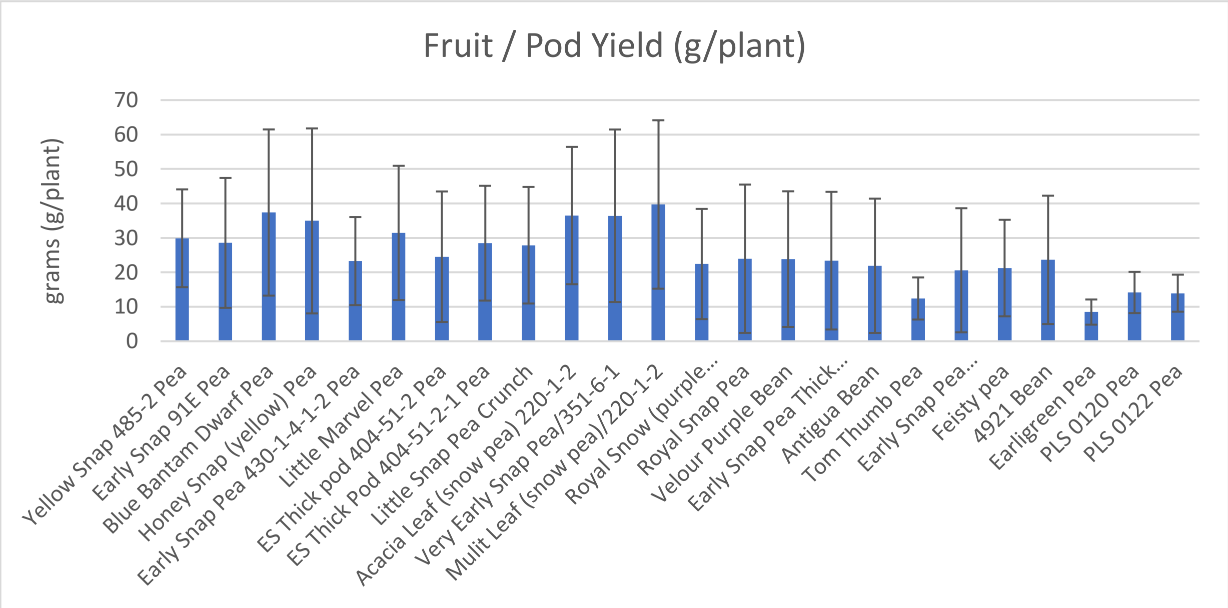

Figure 3. Average fruit/pod fresh mass yield from each plant during harvest. Error bars represent standard deviation (n=4).

E. Nutritional Analysis

Fresh legume fruit were packed and shipped to Eurofins Nutritional Analysis Center to be analyzed for elemental, proximate, and vitamin content. All plant materials were analyzed whole except ‘Tom Thumb’, the only cultivar selected where, culinarily, it is consumed as shelled pea so therefore submitted as such.

Proximate and vitamin results can be seen in **Table 1** All cultivars contained 0.67-1.25% ash, which is any inorganic material, such as minerals, present in the fruit tissue. Brightly colored ‘Yellow Snap’ and deeply hued ‘Royal Snap’ contained the highest amount of vitamin C, with 11.6 and 9.94 mg/100 g, respectively. ‘Tom Thumb’ had the lowest moisture content (71.1%), was the most calorically dense (113 kcal/100 g) and contained the highest amounts of protein (8.44%), crude fat (0.44%), and vitamin B1 (0.187 mg/100 g).‘4921’ contained the highest amount of vitamin K (0.37 µg/g). Ca, Mg, K, and P are all considered key elements for supplementing astronaut nutrition by the NASA Human Research Program.[5] Elemental results can be found in **Table 2**. ‘Royal Snap’ contained the highest amount of Ca (0.081%) and Mg (0.050%), while ‘Tom Thumb’ had the highest amount of P (0.168%) and Bean ‘4921’ had the highest amount of K (0.506%). Iron is a necessary co-factor for many critical enzymatic systems, such as hemoglobin content in blood. However, high iron levels in astronauts after prolonged exposure to microgravity have been implicated in accelerating bone loss.[15,16] Iron concentration was low in all cultivars, with concentrations being the lowest in ‘Royal Snap’ and ‘Yellow Snap’. Sulfur content was low or below detection limit in all cultivars. Highest content was found in ‘Tom Thumb’ (0.04%).

Table 1. Values (fresh mass basis) of legume proximate and vitamin content.

	Proximate Tests						Vitamin		
Cultivar	Ash (%)	Calories (kcal/100 g)	Carbohydrates (Calculated-%)	Crude Fat (%)	Moisture (%)	Protein (%)	B1 (mg/100 g)	C (mg/100 g)	K (µg/g)
Royal Snap	0.82	67	11.86	0.31	82.7	4.31	0.107	9.94	0.18
Yellow Snap	0.67	48	8.45	0.19	87.5	3.19	0.113	11.6	0.16
Velour Purple	0.94	50	9.44	0.13	86.8	2.69	0.031	4.98	0.28
Bean '4921'	1.25	49	8.44	0.22	86.9	3.19	0.049	3.19	0.37
Antigua	1.11	42	6.67	0.23	88.8	3.19	0.029	2.89	0.23
ES Thick Pod 404-51-2	0.82	57	10.18	0.24	85.2	3.56	0.106	9.53	0.20
ES Thick Pod 404-51-2-1	0.85	69	12.55	0.30	82.3	4.00	0.109	7.27	0.21
Tom Thumb	1.10	113	18.92	0.44	71.1	8.44	0.187	7.03	0.27

Table 2. Values (fresh mass basis) of legume elemental content.

Cultivar	Ca (%)	Fe (%)	Mg (%)	P (%)	K (%)	S (%)
	Elemental Content					
Royal Snap	0.081	0.0006	0.050	0.072	0.271	<0.02
Yellow Snap	0.067	0.0006	0.033	0.071	0.224	<0.02
Velour Purple	0.077	0.0009	0.039	0.068	0.340	0.02
Bean '4921'	0.074	0.0007	0.037	0.073	0.506	0.02
Antigua	0.058	0.0007	0.032	0.058	0.390	<0.02
ES Thick Pod 404-51-2	0.075	0.0008	0.040	0.080	0.283	<0.02
ES Thick Pod 404-51-2-1	0.073	0.0009	0.040	0.088	0.296	<0.02
Tom Thumb	0.023	0.0015	0.046	0.168	0.412	0.04

F. Organoleptic Analysis

Sensory panelists (n = 27) were presented with washed whole fruit samples. For cultivars that required shucking, this was done prior to presenting to panelists. They were then asked to rate them using a 9-point hedonic scale (1=Dislike extremely, 2=Dislike very much, 3=Dislike moderately, 4=Dislike slightly, 5=Neither like nor dislike, 6=Like slightly, 7=Like moderately, 8=Like very much, 9=Like extremely) for overall acceptability, appearance, color intensity, aroma, flavor, and texture. Just about right (JAR) scales measure the appropriateness of the level of a specific attribute. Here, they were used to measure crunchiness, juiciness, freshness, sweetness, and bitterness. All JAR were rated on a scale of 1 to 5, with 1 being the least desirable attribute and 5 being the most desirable. The results of the panel assessments and standard deviation are shown in **Table 3** and **Table 4**. These results indicate that the majority of the produce was acceptable for the panelists, with nearly all assessments being 6.0 (slightly like) or greater. ‘Early Snap 404-51-2’ and ‘Early Snap 404-51-2-1’ had higher scores in all sensory attributes than the other cultivars. Both were described as a great balance of sweet, fresh, and crunchy, with the data reflecting those comments (**Table 3**). ‘Tom Thumb’ and ‘Velour Purple’ were the lowest ranking samples. Based on rating and taster comments, issues with ‘Tom Thumb’ included a slight bitterness that created a lingering aftertaste and the flavor of the peas changing from bite to bite. ‘Tom Thumb’ appeared to be a polarizing sample due to the high standard deviation in overall acceptability. This flavor change between bite has been attributed to some peas being slightly more overripe than others. The dark purple color of ‘Velour Purple’ proved off-putting to tasters. It was also fibrous and described as tough to chew, with a bitter aftertaste.

Table 3. Summary of sensory analysis attributes judged on a 9-point Hedonic scale for 8 cultivars of pea and bean. Values are means ± standard deviation (n=27).

	Attribute					
Cultivar	Overall	Appearance	Color Intensity	Aroma	Flavor	Texture
Early Snap 404-51-2	8.06 ± 0.9	7.59 ± 1.3	8.25 ± 1.0	6.37 ± 1.6	8.59 ± 1.8	8.19 ± 1.0
Early Snap 404-51-2-1	8.03 ± 0.8	7.78 ± 1.3	8.06 ± 0.9	6.84 ± 1.6	8.19 ± 1.0	8.19 ± 1.0
Yellow Snap	7.26 ± 1.5	7.26 ± 2.0	6.93 ± 2.2	5.96 ± 1.4	7.37 ± 1.5	7.78 ± 1.5
Antigua	6.34 ± 1.9	7.25 ± 1.5	7.69 ± 1.2	6.03 ± 1.4	5.81 ± 2.1	6.97 ± 1.9
Royal Snap	6.34 ± 1.8	6.28 ± 2.2	6.31 ± 2.2	6.03 ± 1.4	6.06 ± 1.9	6.47 ± 1.9
4921 Bean	6.11 ± 1.6	7.11 ± 1.8	7.67 ± 1.4	5.67 ± 1.1	5.92 ± 1.9	6.89 ± 1.8
Tom Thumb	5.93 ± 2.2	7.07 ± 1.5	7.15 ± 1.5	5.59 ± 1.3	5.26 ± 2.4	7.04 ± 1.8
Velour Purple	5.52 ± 1.9	5.74 ± 2.2	5.74 ± 2.5	5.22 ± 1.5	5.07 ± 1.9	6.41 ± 2.2

Table 4. Summary of "Just About Right" (JAR) attributes judged on a 1 to 5 scale for 8 cultivars of pea and bean. Values are means ± standard deviation (n=27).

	JAR Attributes				
Cultivar	Crunchiness	Juiciness	Freshness	Sweetness	Bitterness
Early Snap 404-51-2	3.00 ± 0.4	3.06 ± 0.3	3.00	3.03 ± 0.6	3.63 ± 0.4
Early Snap 404-51-2-1	3.00 ± 0.3	3.06 ± 0.2	3.00 ± 0.3	2.97 ± 0.5	3.06 ± 0.4
Yellow Snap	3.07 ± 0.3	2.96 ± 0.4	2.96 ± 0.3	2.70 ± 0.5	3.18 ± 0.4
Antigua	3.00 ± 0.4	2.59 ± 0.6	2.94 ± 0.5	2.28 ± 0.8	3.75 ± 0.6
Royal Snap	2.66 ± 0.5	2.53 ± 0.7	2.81 ± 0.7	2.19 ± 0.6	3.34 ± 0.5
4921 Bean	2.96 ± 0.6	2.59 ± 0.7	2.96 ± 0.4	2.30 ± 0.7	3.63 ± 0.7
Tom Thumb	3.15 ± 0.4	2.67 ± 0.6	3.15 ± 0.7	2.19 ± 0.7	3.93 ± 0.7
Velour Purple	3.04 ± 0.6	2.44 ± 0.6	2.96 ± 0.8	2.19 ± 0.7	3.74 ± 0.9

V. Discussion

Of the 24 pea and bean cultivars tested, only five were of appropriate height to grow in APH and Veggie. Several others were close and adjusting horticultural practices could shorten their stature. APH has a very shallow root tray (science carrier) and has the ability to adjust RGB-W/FR LEDs. Cultivation under a blue-rich lighting spectrum[17], decreasing rooting volume[18], and limiting nitrogen in fertilizer[19,20] could all be options for decreasing canopy height, allowing for more cultivars to be tested in these facilities.

For varieties where the pods are shucked and only the pea seeds are consumed, the amount of time required for shucking seemed excessive and unacceptable. The pay off, edible peas, was miniscule, and the inedible waste (shells) was excessive (**Figure 6**). The nutritional value of the pea seeds, while high in protein ('Tom Thumb'; **Table 1**), does not justify the harvest, preparation time, and volume of waste. Hence, we suggest forgoing these pea seed varieties in lieu of cultivars whose fruit (pods and seeds) can be consumed entirely.

For the most part, pea and bean varieties tested by the sensory panel were well received. The poor palatability of 'Tom Thumb' is attributed to the samples being over-ripe. Increasing harvest frequency would increase crew time, which is in short supply. With the extended preparation time, coupled with the knowledge that harvest occurrences must be accelerated to achieve the highest quality product, peas of this type seem to be a poor choice for space applications.

All cultivars started at CRL 1 (Basic Crop Testing). This testing progressed the down-selected varities to CRL 3. To further these legumes along the CRL, the focus of any future testing should be on seed sterilization, varieties whose fruit is entirely edible, with testing in space or space analogous hardware, along with the determination of an applicable fertilizer regimen.

Appendix

Table 5. Pea and bean cultivars tested in controlled environment and their fruit precent dry mass (DM).

Cultivar	Scientific Name	Fruit %DM
PLS 0120	*Pisum sativum*	22.1%
PLS 0122	*Pisum sativum*	18.6%
Antigua	*Phaseolus vulgaris*	11.5%
4921	*Phaseolus vulgaris*	12.7%
Very Early Snap Pea/351-6-1	*Pisum sativum*	18.3%
Early Snap Pea Thick Pod/404-35-1-2-1	*Pisum sativum*	19.0%
Early Snap Pea, Dark Green/412-1-1	*Pisum sativum*	17.6%
Honey Snap (yellow)/274-1-2-1	*Pisum sativum*	14.6%
Acacia Leaf (snow pea)/299	*Pisum sativum*	16.5%
Mulit Leaf (snow pea)/220-1-2	*Pisum sativum*	15.1%
Royal Snow (purple snow)/99-7-1-1	*Pisum sativum*	13.6%
Feisty pea	*Pisum sativum*	18.6%
Early Snap Pea/91E	*Pisum sativum*	12.7%
Early Snap Pea Thick Pod/404-51-2	*Pisum sativum*	12.7%
Early Snap Pea Thick Pod/404-52-2-1	*Pisum sativum*	13.5%
Early Snap Pea/430-1-4-1-2	*Pisum sativum*	13.1%
Royal Snap (purple snap)/337-1-1-3	*Pisum sativum*	14.4%
Yellow Snap/485-2	*Pisum sativum*	12.7%
Tom Thumb	*Pisum sativum*	18.9%
Earligreen	*Pisum sativum L.*	21.9%
Blue Bantam Dwarf	*Pisum sativum*	15.8%
Little Snap Pea Crunch	*Pisum sativum*	11.8%
Little Marvel	*Pisum sativum*	17.0%
Velour Purple	*Phaseolus vulgaris*	12.2%

Figure 2. Down-selected short legume varieties '4921' Snap (22.2±3 cm height, 23.61g/plant/harvest), 'Velour Purple' (22.63±1.24 cm height, 23.83g/plant/harvest), 'Tom Thumb' (17.25±7.79 cm height, 12.42g/plant/harvest) and 'Antigua' (38.25±4.94 cm height, 21g/plant/harvest). Cause of yellow upper canopy leaves in Antiqua is unknown.

Figure 3. Down-selected tall varieties, 'Yellow Snap' (62±8.22 cm height, 30g/plant/harvest), 'Royal Snap' (62.75±7.43 cm height, 24g/plant/harvest), 'Early Snap Thick Pod 404-52-2' (49.25±2.68 cm height, 25g/plant/harvest), and 'Early Snap Thick Pod 404-51-2-1' (55±0.71 cm height, 30g/plant/harvest).

Figure 4. 'Tom Thumb' (a) shelled peas and (b) whole pods. (c) 'Royal Snap'.

Figure 5. Fruit from down-selected legumes. 'Royal Snap' not pictured.

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