

Selection of Leafy Green Vegetable Varieties for a Pick-and-eat Diet Supplement on ISS

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NASA Human Research Program (HRP) Advanced Food Technology Project

Mitigate the Risk of Performance
Decrement and Crew Illness Due to an
Inadequate Food System by providing:

- Safe, nutritious food that meets spaceflight requirements
- Sensory acceptability and variety
- Balance with resource constraints

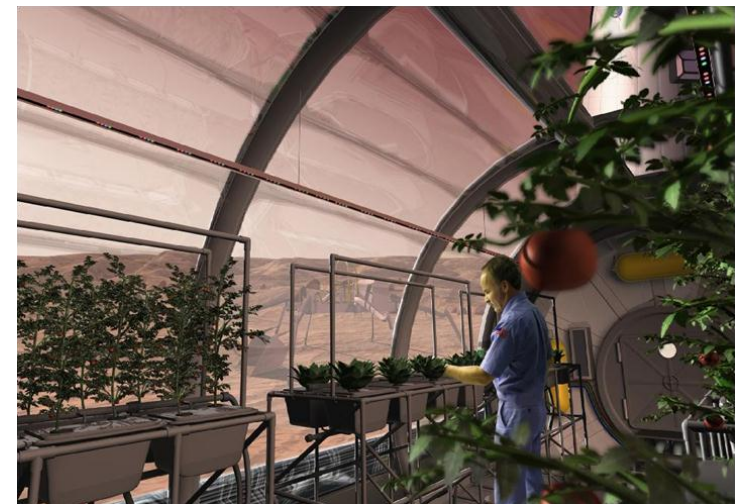
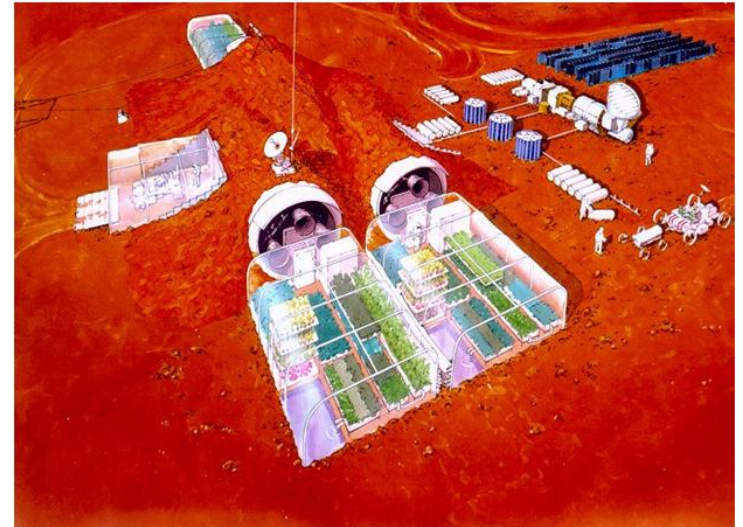
**The current processed and prepackaged food system is not adequate in some nutrients or in acceptability for long duration mission scenarios (3-5 years).



HRP Long Duration Food System Research Plan

- Continuing research to improve prepackaged system
 - Requires least crew time on exploration mission
- Supplement with pick and eat salad crops
 - Improves variety, nutrition
 - May benefit crew psychosocial health

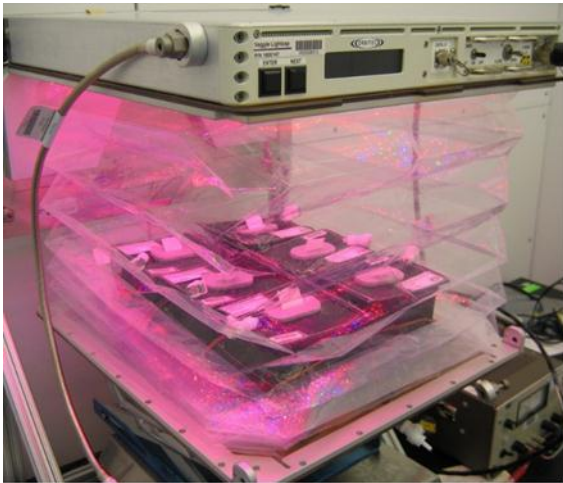
****Any plant implementation into the life support system near term will be most beneficial if they also have pick and eat nutritional value**



Pick and Eat Crop Selection Study:

Aim: To down select crop candidates for crew to grow, pick, and eat on ISS to supplement a packaged diet.

ISS crop production would likely use the Veggie hardware or a similar growth system.



Veggie is currently on ISS in the Columbus module.



ISS Cmdr. Swanson harvesting lettuce from the Veggie test– June, 2014

“Leafy Green” Crops Studied:

- ‘Tyee’ spinach
- ‘Flamingo’ spinach
- ‘Outredgeous’ Red Romaine lettuce
- ‘Waldmann’s Dark Green’ Leaf lettuce
- ‘Bull’s Blood’ beet
- ‘Rhubarb’ Swiss chard
- ‘Tokyo Bekana’ Chinese cabbage
- Mizuna



Selection Criteria Overview

- Horticultural factors
 - Germination, ease of growth, amount of growth (food), size
- Dietary factors
 - Percent dry matter
 - Elemental Factors - Composition of key elements (K, Fe, Ca, Mg)
 - Nutrient Factors - Beneficial phytonutrients (Vitamin K, Lutein, Zeaxanthin, Antioxidants)
- Organoleptic factors
 - 9-pt Hedonic Scale: Overall taste, Appearance, Color, Bitterness, Flavor, Texture
 - 5-point Just About Right Scale: Crispness, Tenderness

Weighting and Ranking

- Weighting factors were developed for each parameter based on subjective importance.
- Data were normalized, weighted, and ranked.
- Divided into:
 - Horticultural Factors
 - Elemental Factors
 - Nutrient Factors
 - Organoleptic Factors
- 8 varieties were down selected to 4 for nutrient and organoleptic evaluation.
- 4 crops were grown and shipped to JSC for organoleptic testing.
- Final ranking performed on down selected crops.

Growth Studies

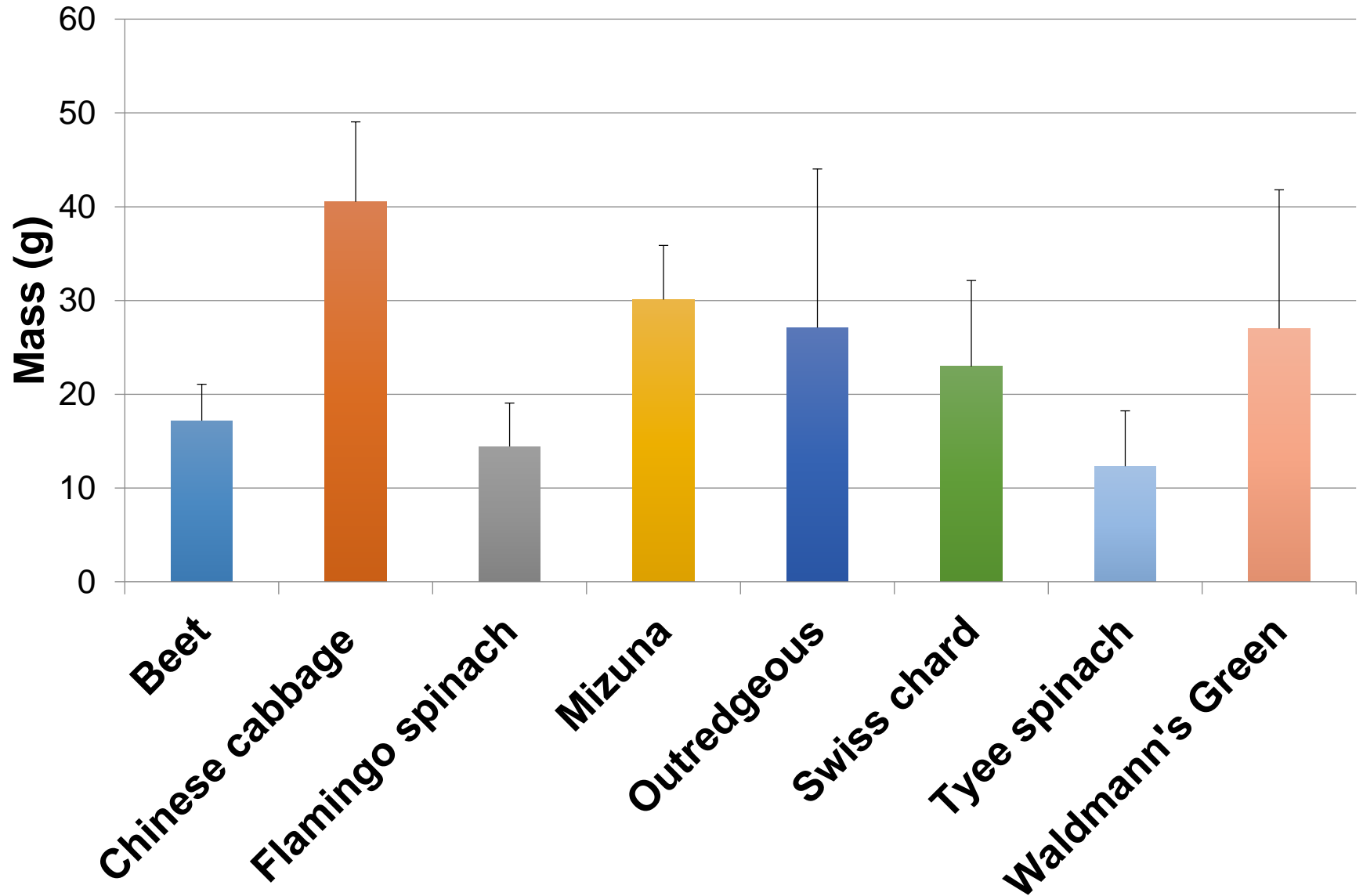
Plants grown in a controlled environment chamber at KSC

Condition	Day	Night
Photoperiod	16 hours	8 hours
Temperature	23°C	18°C Test 1 23°C Test 2
Relative Humidity	70%	70%
CO ₂	1000 ppm	1000 ppm
Light - CWF	~400 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$	-

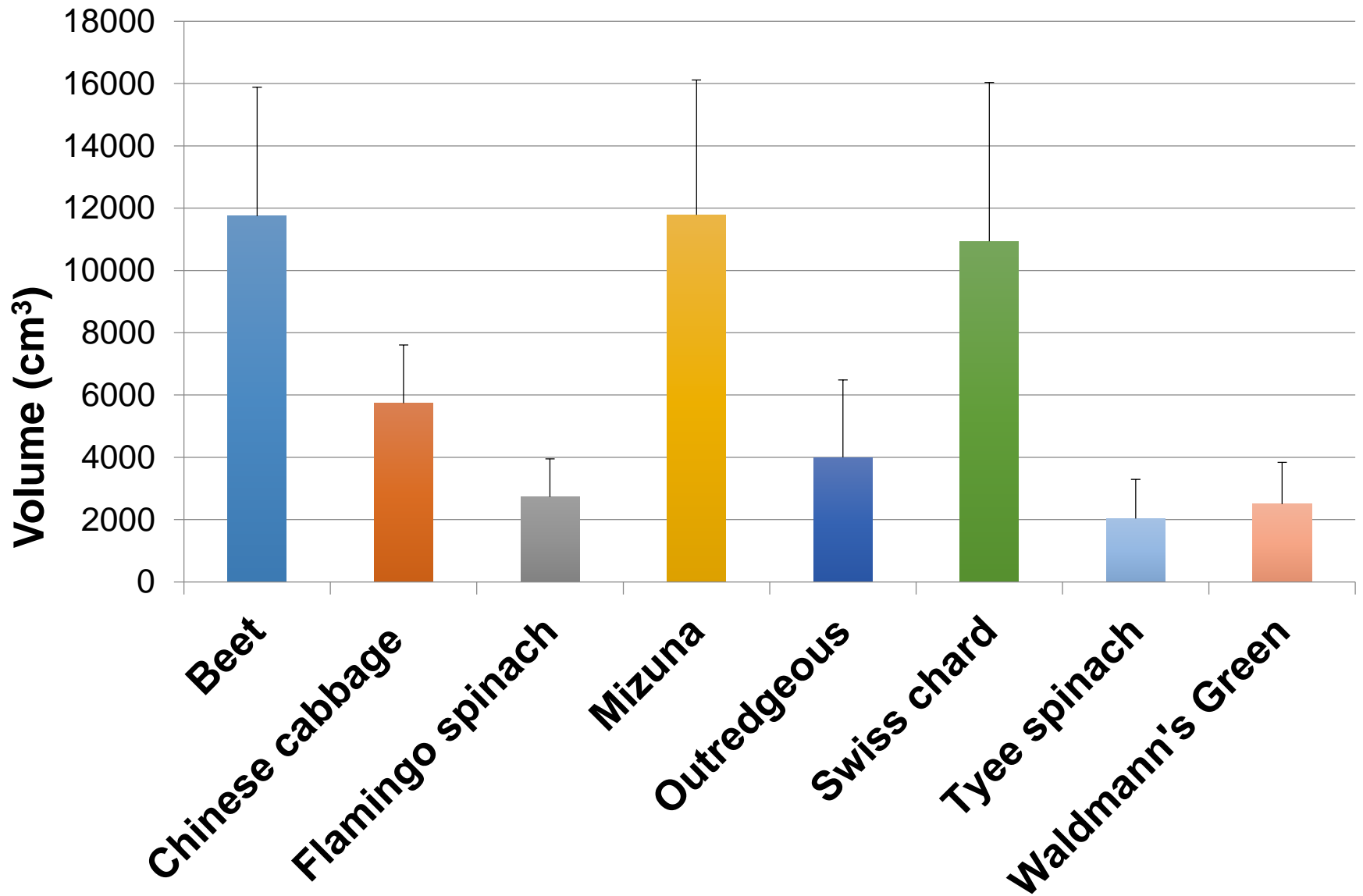
In test 2
eliminated
thermoperiod
to be similar to
Veggie



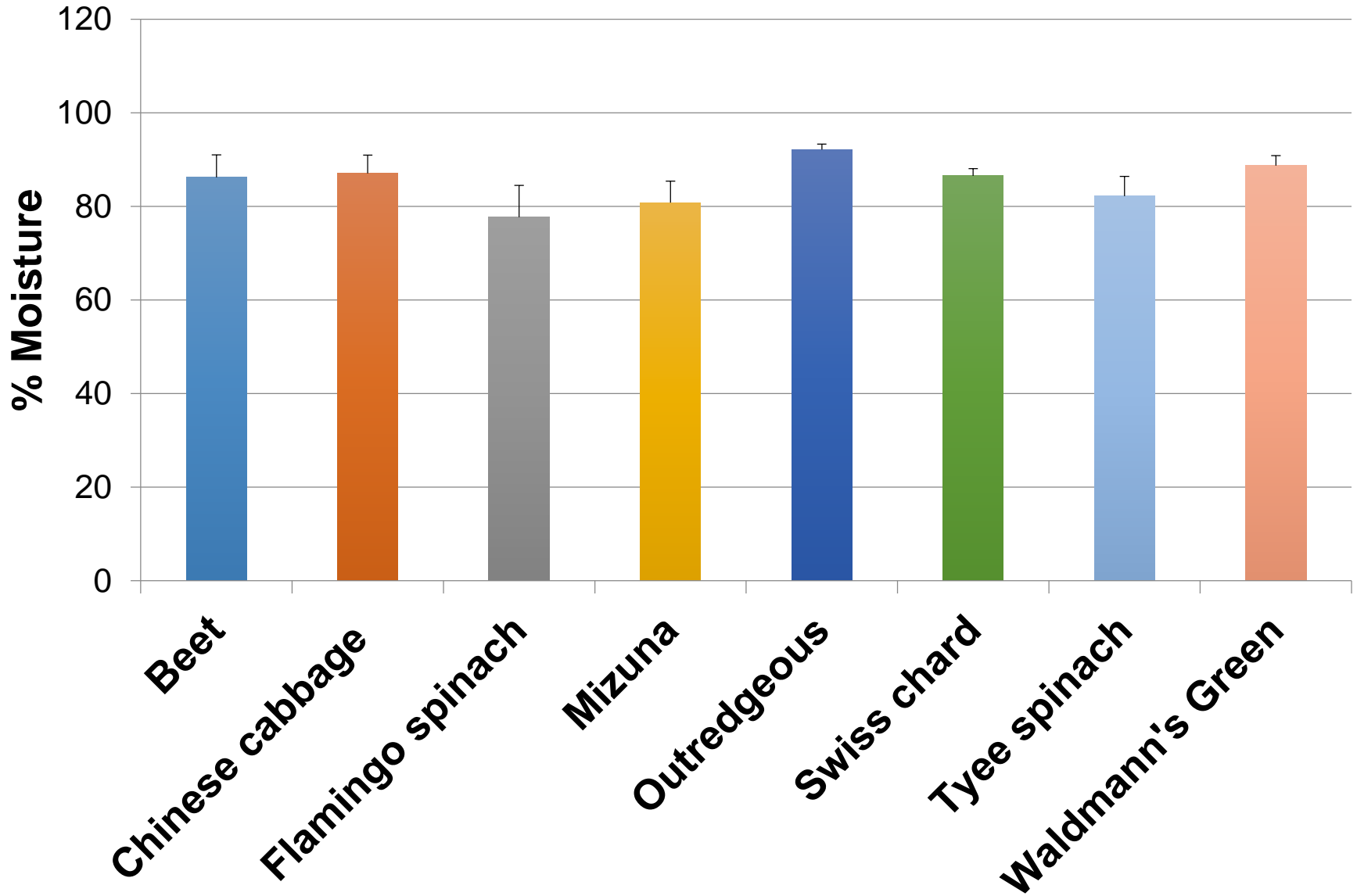
Fresh Mass



Volume *(from diameter and height measurements)*



Moisture Content



Elemental Analysis

	Ca	Fe	K	Mg
	(µg/g DM)			
Beet	14787.05 ^{a,b}	286.51 ^a	30416.27 ^a	25843.99 ^a
Chinese cabbage	17068.20 ^b	6.79 ^b	20036.45 ^b	7993.75 ^b
Spinach (Flamingo)	8493.08 ^{a,c,d}	47.52 ^b	12854.27 ^b	9966.16 ^b
Mizuna	14140.41 ^{a,b}	16.73 ^b	16964.88 ^b	6761.41 ^b
Lettuce (Outredgeous)	8168.93 ^{c,d}	14.02 ^b	36169.85 ^{a,c}	6541.36 ^b
Swiss chard	14332.48 ^{a,b}	65.02 ^b	26887.21 ^{a,d}	17808.77 ^c
Spinach (Tye)	8601.98 ^d	36.60 ^b	22427.80 ^{a,b}	10990.26 ^b
Lettuce (Waldman's Green)	5916.18 ^d	20.85 ^b	23656.95 ^{a,b}	4467.57 ^b

Crop	Plant Growth Factors	Plant Growth Rank	Elemental Factors	Elemental Rank	Plant Growth + Elemental	PG+E rank
'Bull's Blood' beet	2.30	8	3.80	2	6.10	6
'Tokyo Bekana' Chinese cabbage	6.26	1	3.36	4	9.62	1
'Flamingo' spinach	2.52	7	1.94	8	4.46	8
Mizuna	5.05	2	2.68	6	7.73	3
'Outredgeous' lettuce	4.23	4	3.73	3	7.96	2
'Rhubarb' Swiss chard	3.45	5	3.94	1	7.39	4
'Tye' spinach	2.94	6	2.83	5	5.77	7
'Waldmann's Green' lettuce	4.82	3	2.31	7	7.12	5

Nutrient Analysis

	ORAC	Lutein	Zeaxanthin	Vit. K
	μmol TE/g	mg/g	mg/g	mg/100g
Beet	ND*	ND	ND	ND
Chinese cabbage	156.41 ^a	2.28 ^a	0.02 ^a	0.65 ^a
Spinach (Flamingo)	ND	ND	ND	ND
Mizuna	121.84 ^a	3.87 ^b	0.02 ^a	2.32 ^b
Lettuce (Outredgeous)	1119.59 ^b	3.16 ^b	0.02 ^a	0.16 ^c
Swiss chard	1107.80 ^b	5.94 ^c	0.04 ^a	0.79 ^d
Spinach (Tye)	ND	ND	ND	ND
Lettuce (Waldmann's Green)	ND	ND	ND	ND

Organoleptic Factors

9-point
Hedonic
Scale

Attribute	Chinese cabbage	'Mizuna'	'Outredgeous' lettuce	Swiss chard
Overall Acceptability	7.23 (1.42)	6.89 (1.18)	6.69 (1.79)	6.51 (2.12)
Appearance	8.10 (1.05)	7.29 (1.73)	7.66 (1.53)	8.51 (0.89)
Color Intensity	8.34 (0.94)	8.03 (1.18)	7.77 (1.46)	8.57 (0.85)
Bitterness	6.03 (1.524)	6.23 (1.46)	6.14 (1.54)	6.09 (1.50)
Flavor	7.11 (1.64)	6.83 (1.36)	6.51 (2.13)	6.14 (2.58)
Texture	7.97 (1.12)	7.31 (1.32)	6.66 (1.97)	7.31 (1.63)

1= Like Extremely, 9=Dislike Extremely

5-point Just
About Right
Scale
(with 3=Just
About Right)

Attribute	Chinese cabbage	'Mizuna'	'Outredgeous' lettuce	Swiss chard
Crispness	3.0 (0.0)	2.94 (0.23)	2.46 (0.51)	2.97 (0.17)
Tenderness	3.0 (0.0)	2.94 (0.34)	3.31 (0.47)	2.94 (0.42)

Numbers are means (Standard Deviations) of N=35 tasters

Final Normalized Ranking

Crop	Nutrients	Nutrient Rank	Organol. Factors	Organol. Rank	Overall	Overall Rank
'Tokyo Bekana' Chinese cabbage	0.63	4	8.05	1	18.30	1
Mizuna	2.15	2	5.64	2	15.52	3
'Outredgeous' lettuce	1.96	3	1.93	4	11.85	4
'Rhubarb' Swiss chard	4.92	1	4.55	3	16.86	2

Next Steps

- Prepare top candidates for flight testing in Veggie
 - Grow top candidates in Veggie in plant pillows
 - Microbiology assessment
 - Seed sanitation
 - Red and Blue LED light testing
 - Work to manifest and fly
- Similar down selection underway with dwarf pepper and tomato varieties



Thank you!



Backup



Parameter	Weighting	Rationale
Plant Growth Factors		
Germination	x 1.5	Germination indicates how easy plants are to grow.
SPAD	x 0	SPAD is a factor of plant growth (chlorophyll content) but not important for diet or a yield parameter
Volume	x 1.5 (inverted)	Volume is important because it gives information on how much space the crop will occupy and it is a constraint for spaceflight
FM	x 2	Fresh mass indicates crop yield - a principal factor
Days to maturity	x 1.5 (inverted)	Indicates how quickly plants could be grown
% moist	x 1 (inverted)	Percent moisture indicates amount of dry mass ~calories
Elemental Factors		
Ca	x 1	Calcium is important but desired amount remains unclear
Fe	x 1.5 (inverted)	Too much iron can cause issues so low iron is desired
K	x 2	Space diet is deficient in Potassium - a principal factor
Mg	x 1.5	More Magnesium is desirable

Parameter	Weighting	Rationale
Nutrient Factors		
ORAC	x 1.5	Antioxidants may help protect from radiation damage
Lutein	x 1.5	Lutein is potentially important for eye health
Zeaxanthin	x 1.5	Zeaxanthin is potentially important for eye health
Vitamin K	x 1.5	The space diet is deficient in Vitamin K which does not survive storage well
Organoleptic Factors		
Overall taste	x 2	Overall taste is a principal factor
Appearance	x 1	Appearance is not important as long as it is acceptable
Color	x 1	Color is not important as long as it is acceptable
Bitter	x 1	Bitterness might be good or bad
Flavor	x 1.5	Flavor is important
Texture	x 1	Texture is not important as long as it is acceptable
Crispness	x 1	Crispness is not important as long as it is acceptable
Tenderness	x 1	Tenderness is not important as long as it is acceptable