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D 2.4 – Plant Analysis Report

prepared for

WP 2.2 – Plant Analysis

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Table of contents

Acronyms

Acronym	Explanation	Acronym	Explanation
BLSS	Bio-regenerative Life Support Systems	ISPR	International Standard Payload Rack
CEA	Controlled Environment Agriculture	ISS	International Space Station
DLO	Wageningen University and Research	PAR	Photosynthetic Active Radiation
DLR	German Aerospace Center	RH	Relative humidity
EDEN	Evolution & Design of Environmentally-closed Nutrition-Sources	VBAm	Visual Basic Applications macros
FEG	Future Exploration Greenhouse	WP	Work Package
HI	Harvest index		

1 Introduction

In order to further planetary exploration, new technologies have to be developed to overcome the physical and psychological challenges of space exploration, such as regulating the interior environment of spaceships, maintaining the astronauts' physical and psychological health, and the provision of water, oxygen and food. Since the beginning of space exploration, human life support has been one of the most important challenges. For short-term missions, problems were solved in the past by a controlled atmosphere combined with food and water transportation from Earth. However, these solutions are ineffective for long-term space exploration since the resupply from Earth is not an option. Therefore there is need for Bio-regenerative Life-Support Systems (BLSS) that will reduce and ultimately eliminate the need for resupply of foods from Earth. According to Salisbury (1999), the down side of this kind of system resides in the complexity and difficulty to maintain a proper composition of the atmosphere while also providing food.

The International Space Station (ISS) serves as a research laboratory and there, much of the testing of plant cultivation to date has focused on controlling the environment to meet the plants' needs. Bio-regenerative life support studies have shown that many traditional field crops such as wheat, soybean, potato, sweet potato, and rice can be grown effectively in plant growth chambers (reviewed by Wheeler, 2003), which suggests that ready to eat crops can be successfully cultivated in space. However, these studies were focused on the physical constraints of the plant. For example, if growing systems in space, small species or dwarf cultivars would be desirable. Crops with a high Harvest Index (the weight of a harvested product divided by the total plant weight of a crop) would provide higher edible yield per unit volume while minimizing solid waste production (inedible biomass). The processing and recycling of inedible biomass also requires O_2 (Wheeler, 2003).

In addition to the cultivation of plants and their physical constraints, plants can also have a positive psychological impact on humans in confined environments.

Eating food is a fundamental requirement for survival and plays a main role in the maintenance of good physical and mental health. The microgravity environment in space requires special dehydrated foods, which are very different and less variable than what astronauts are used to eat on Earth. Furthermore, the microgravity environment causes chemosensory alterations in the human body, leading to a reduced flavor perception. Consequently, the psychological well-being of astronauts operating on long-term space missions could potentially be affected. While the relationship between eating fresh food and the mental well-being of astronauts has not been properly addressed, astronauts frequently have a craving for fresh food 'with a bite'. Therefore this work package involves the process of selecting plants to be grown on-board the ISS and is aimed not only to produce fresh and tasty food for the astronauts, but also to contribute to their psychological wellbeing.

The purpose of this work package is the development and application of a methodology to select plants for cultivation at the Neumayer III Antarctic station and on-board the ISS aimed at enhancing the psychological well-being of expeditioners and astronauts by providing them with fresh food supplements in the form of fruits, herbs and/or vegetables. The methodology takes (human) quality, physical and plant aspects into account. The methodology includes a framework for the selection process, a list of relevant criteria based on plant characteristics, engineering constraints and human nutrition and psychology. It entails scoring systems to assess these criteria for each plant including their weighting factors to rank the choices.

A methodology is preferred over a simple list of plants, because it can be adapted later on. It allows plants that were not originally included in the analysis to be evaluated. This does not only mean that new species can be evaluated but also that new cultivars, for example shorter tomato plants, can be selected or even bred for. It is of great importance that the methodology is flexible so that it can be adjusted when situations change. It must be flexible because there will likely be changes in conditions before and during the implementation of the plant production facilities on-board the ISS and on future space missions.

2 Crop choice

2.1 Facilities

The choice of plants is determined in part by the facility in which they are to be grown, either the International Standard Payload Rack (ISPR) or the Future Exploration Greenhouse (FEG).
ISPR: a small cultivation rack for use in the ISS. It houses all necessary support systems for cultivation of higher plants. All the necessary controlled environment agriculture (CEA) technologies will be integrated into the ISPR, i.e. plant accommodation, volatile organic compound (VOC) separation, nutrient delivery system, plant health monitoring sensors, bio-detection system and decontamination.
FEG: a test environment to conduct innovative plant cultivation. This is a larger experimental system for use at the Neumayer Station III in Antarctica. Special cultivation techniques will enable the production of larger quantities of fresh food for the crew, in order to investigate the different psychological aspects that higher plants have on isolated crews. The FEG uses similar technologies as those in the ISPR, but in a scaled-up configuration.

2.2 Basis for choice

The constraints each crop must comply with (hard constraint) or conditional constraints (soft constraints) were considered differently of course, but also differently in relation to the facility in which they are to be cultivated. Hard constraints are compulsory, but differ between the FEG and ISPR. Both types of constraints within the three main aspects considered to be important, yield, production and quality are indicated in Table 2-1.
Based on the hard constraints defined within the methodology, a provisional list of 15 crops was drawn up that could be cultivated in the conditions at Neumayer III and/or ISS.

Lettuce	Bell pepper	Radish	Chives
Tomato	Water cress	Spinach	Basil
Dwarf tomato	Red mustard	Strawberry	Coriander
Cucumber	Swiss chard	Parsley	

Table 2-1. List of hard and soft constraints within the aspects yield, production and quality.

Yield (score)	Hard	Soft	**Production** (score)	Hard	Soft	**Quality** (score)	Hard	Soft
Harvest index (0-1)		X	Commercial cv available	X		Edible	X	
Space/time efficiency (kg/m^3/d)		X	Max. height 2 m	X		Ready-to-eat	X	
Light/energy use efficiency (g/µmol)		X	Suitable for production system	X		No alternative form available	X	
			Light [1)] <600 µmol/m^2/s	X		Texture (0-1)		X
			First harvest < mission time	X		Taste (0-1)		X
			Disease resistance (0-1)		X	Pungency (0-1)		X
			Reasonable shelf life (0-1)		X	Appearance (0-1)		X
			Min. handling time (0-1)		X			

	Spread harvest (0 or 1) X	

1) Is a light intensity of less than 600 µmol/m²/s suitable to grow this crop

If these plant species have met the hard constraints, the methodology can be used to select plants suitable for cultivation in the FEG or ISPR. In order to do this, the main aspects and soft constraints can be weighted and ranked in order of importance.

2.3 Description of methodology

The designed methodology aims to be objective in preventing suboptimal selection of plants due to personal bias. Having a methodology saves time in the selection of crops as it takes into account the most important constraints involving (human) quality, plant and physical factors and can be reused for different purposes in other types of missions, i.e. Neumayer III or ISS. Careful analysis of the results can lead to the future development of breeding guidelines for new cultivars that would be better suited for growing in space.

2.3.1 Criteria for plant selection

The basis for plant selection for the EDEN ISS project is an analysis of a number of selection criteria considered to be important for these missions. These are (human) quality aspects and plant/crop aspects, i.e. yield and production.

a) **Yield** aspects. These aspects combine yield and efficiency in time and space, and were limited to harvest index, light use efficiency and space/time efficiency. The last criteria focusses on the volume required to grow a plant/crop, the time from sowing to first harvest and the amount of harvest realized.
b) **Production** aspects. These aspects are concentrated on the physical dimensions and constraints of the growth modules at Neumayer III and ISS and the necessary technical aspects of cultivation. The criteria used were growing conditions (light, temperature, humidity, CO_2), labor requirements (seed treatment, germination, transplantation, pollination, pruning and harvesting), disease control and shelf life.
c) Human **quality** aspects. Selection criteria were defined in a way that eventually it is possible to select plants with the greatest benefits for astronauts. The criteria taken into account were taste, texture, appearance and pungency. Other criteria like nutritional value, allergic potential and digestive quality were not taken into account.

2.3.2 Methodological framework

The methodological framework used for the selection of plants was based on a number of existing frameworks used earlier for selection processes. An extensive literature study resulted in several approaches that could be applied to the plant selection. They then were adapted for use in this particular project by first setting up requirements or constraints as input for the methodology. The first step is to list the requirements and categorize these in main aspects and sub-aspects as indicated in section 2. They were each given a minimum and a maximum value, followed by an implementation of the constraints.

Three methodologies were chosen and combined to create a suitable methodological framework for plant selection. The methods are: the objective tree method, pairwise comparison, and the 0, 1, 2 – method. Without going in a great deal of detail, the methods were used as follows:

a. Objective tree method - this method was designed to determine the relationship between the quality, production and yield aspects. However, we have adapted this method to be used to assess if a plant meets all the hard constraints that apply to the ISPR or the FEG.

b. Pairwise comparison – this method can be used to prioritize the different objectives (David, 1963). All objectives are compared to every other objective to define the weighting factor of each of the different objectives.
c. 0, 1, 2 - method - the 0, 1, 2 – method was used by Hoff et al. (1982) to rank plant species to grow in a controlled ecological life support system. A simple scoring system was applied to indicate the compatibility of the plants: the crop is compatible with a particular criteria (score 2), minor problems must be overcome (score 1), major problems must be overcome (score 0).

The three selection methods were combined to produce a suitable methodology for the EDEN ISS plant selection. The methodology was performed by a group of researchers at Wageningen UR Greenhouse Horticulture, schooled in plant physiology and plant responses to greenhouse environmental conditions.
First, the decision tree was used to exclude plants that are not compatible with the hard criteria, for example edibility and plant size. Secondly, pairwise comparison was used to weigh the constraints, which we call soft criteria, and identify the ones that were most important. Thereby weighting factors were assigned to each constraint. This method is also used to compare the importance of the aspects and assign them a weight factor. Lastly, the 0, 1, 2 - method was used to weigh the crop's fulfilment of the constraints. The result is that the final score of the crop will be determined by the addition of all the combinations of criteria weights and crop factor of fulfilments. The following explains which part of each existing selection method was used and how they together form one methodological framework.

Objectives tree method elements
The structure of the objectives tree method was used for the exclusion of plants that, based on important constraints, can definitely not be grown on-board the ISS. These important constraints are so called hard constraints. Physical constraints play an important role in this first step as they relate to the fixed requirements of the growth conditions, such as space and light intensity. The decision tree involves only "yes" and "no" parameters to categorize the crops. An example of the structure of the tree is shown in Figure 2-1.

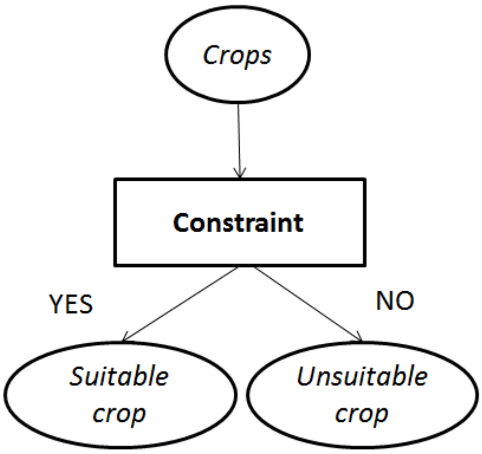

Figure 2-1. Structure of the tree method.

Pairwise comparison elements
Pairwise comparisons were used to determine the importance of the soft constraints. For example, the relative importance of two aspects, production and quality, were compared to the yield aspect. Then, the constraints of each of the three aspects (yield, production and quality) were ranked using the adapted pairwise comparison, thereby assigning scores to the different constraints within the groups of the different aspects. For this the most important constraint in each aspect was selected and the remaining constraints were compared against it. In this way the total weight for a certain constraint can be calculated by multiplying the individual constraint score by relative importance of

the whole aspect. The scales of each table of comparison were normalized to allow comparisons between different tables.

0, 1, 2 - Method elements

The 0, 1, 2 – method was used to score the plants for the individual constraints. However, instead of a 0, 1, 2 - scale, a 0 to 1-scale was applied. The gradual 0 to 1 - scale gives the possibility to not only assign scores based on the plant's compatibility with the constraint, as described earlier, but also to integrate constraints expressed in absolute values. This is necessary for example, for the Harvest Index, which is expressed in a number between 0 and 1. Furthermore, in this way the plant score for a specific constraint could be multiplied with the relative weighting factors of the constraint and aspect so that, in the end, plants could be ranked based on a final crop score between 0 and 1; with 0 being not suitable to grow in space at all and 1 being the perfect plant according to the different constraints.

Developed methodological framework

The crops were first subjected to a test if they fulfil the hard criteria. For this the objective tree method is used. All plants that pass through this first step will continue to the criteria weighting procedure. Either scoring their compatibility with the different constraints with a number from 0 to 1, or in some cases by giving the absolute number of a constraint-related characteristic will do this. This number will be multiplied by the value that was given to the specific constraints by pairwise comparison. The final score of the crops are based on the multiplication of the weight of the constraint and the score of the plant in that constraint, and then these values are added up to rank the final score of the crop. The equation that dictates this procedure is:

$$P_x = A_1(C_{1.1} * S_{1.1} + C_{1.2} * S_{1.2} + \cdots C_{1.n} * S_{1.n}) + A_2(C_{2.1} * S_{2.1} + C_{2.2} * S_{2.2} + \cdots C_{2.n} * S_{2.n}) + A_3(C_{3.1} * S_{3.1} + C_{3.2} * S_{3.2} + \cdots C_{3.n} * S_{3.n})$$

Where P_x is the final crop score, A is the relative importance of the aspect, C is the weight factor of the constraint and S is the score of the crop in that constraint, this is applied for n constraints.

2.3.3 Implementation of the methodological framework

A spreadsheet was developed in Microsoft Excel to support the selection of the plants. It is composed of two input tabs: one where data concerning the constraints can be inserted and another containing a candidate crop list where values for selection criteria can be inserted. Initial values for testing the methodology were taken from Bamsey et al. (2014). The spreadsheet sets up a structure to classify the plants according to their fulfilment of the hard and soft constraints. Plants that do not meet the hard constraints are automatically eliminated from the final list. The rest of the plants are ranked according to the final score formula. Tabs for the comparison of constraints are created and separated per aspect. The aspects are compared in an additional tab. The final weights and scores are then displayed in a results tab. The process and order in which each tab operates and how the different tabs relate to each other is explained in Figure 2-2. Each tab requires input and incorporates the new defined situation, except for the 'results' tab. A new tab called 'results' is created as soon as the information from 'selected crops', 'comparison values' and 'crop scores' have been integrated. They result then in 'results', but then in a new tab.

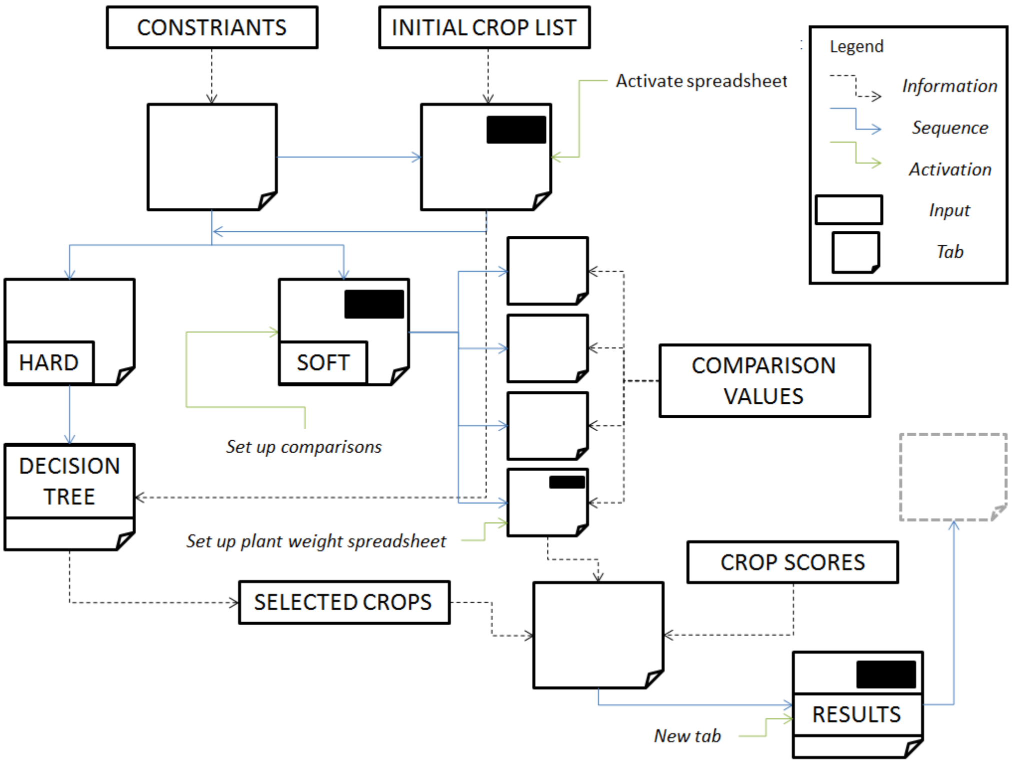

Figure 2-2. Scheme of the selection spreadsheet.

The spreadsheet was developed with the use of Visual Basic Applications macros (VBAm) and is set to process 19 different constraints, classified in 4 different aspects (Physical aspect is used only for hard constraints). The various macros are activated with buttons in some of the tabs. The constraints are added with additional information fields, including: ID number, aspect, system/subsystem and threshold values or target value. The candidate crop list input can contain up to 30 crops. A unique ID number identifies each of the crops.

2.4 Results of methodology

The crops were ranked for the ISPR and FEG systems separately because the hard constraints for each system differ. The main difference between the two is the maximum allowable height in which the crops grow, being ca. 180 cm in the FEG and 60 cm in the ISPR system.
The results for each system are listed in the tables below (Table 2.2 – 2.4), with a separate table for the herbs only.
The ranking of the three main aspects as well as the ranking of the soft constraints within each aspect differed between the FEG and ISPR systems because for each system aspects and constraints differ in relative importance. That resulted in the observed differences between the weighting that resulted from application of the methodology. The weighting is a relative score, with differences in weighting between crops indicating the relative suitability of each crop.

2.4.1 ISPR system

For the ISPR system, aspects were ranked as follows:

Yield > Quality > Production

Within each aspect, parameters were ranked as follows:

Yield: Space/time efficiency > Harvest Index > Light use efficiency
Quality: Taste > Pungency > Texture = Appearance
Production: Spread harvest > Disease Resistance > Handling time > Shelf life

The results of the plant choice methodology are given in Table 2-2.

Table 2-2. Ranking of crops for the ISPR.

Ranking No.	Crop	Weighting	Comment
1	Lettuce	54.1	
2	Dwarf tomato	30.8	Has a relatively low HI
3	Strawberry	19.7	A long growing cycle, requires vernalisation period
4	Radish	19.6	May require some pressure for proper formation
5	Spinach	16.4	
6	Swiss chard	13.1	Less suitable than spinach according to breeders
7	Red mustard	10.2	Spicy
8	Water cress	8.8	Rapid growth, variable taste

Because the ISPR system is very limited in size (area as well as height), the amount of fresh food (yield) was given a higher importance, followed by quality with taste and pungency rated as important, followed by production with spread harvest having the highest priority.

2.4.2 FEG system

For the FEG system, aspects were ranked as follows:

Yield > Production > Quality

Within each aspect, parameters were ranked as follows:

Yield: Light use efficiency > Harvest Index > Space/time efficiency
Production: Disease Resistance > Spread harvest = Handling time > Shelf life
Quality: Taste > Appearance > Pungency = Texture

The results of the plant choice methodology are given in Table 2-3.

Table 2-3. Ranking of crops for the FEG.

Ranking No.	Crop	Weighting	Comment
1	Lettuce	15.3	
2	Cucumber	12.1	Small cultivars best suited, spiral growth system needed
3	Chives	8.8	
4	Tomato	8.6	Spiral growth system needed
5	Dwarf tomato	8.3	
6	Strawberry	6.0	A long growing cycle, requires vernalisation period
7	Radish	5.9	May require some pressure for proper formation
8	Parsley	5.2	
9	Spinach	5.0	
10	Swiss chard	4.3	Less suitable than spinach according to breeders
11	Bell pepper	4.2	Fruit setting is an issue, relatively low HI, slow grower
12	Red mustard	3.5	Spicy
13	Coriander	3.1	
14	Water cress	3.0	Rapid growth, variable taste
15	Basil	1.8	

The main aim of the FEG system is to produce sufficient, and especially regular, amounts of fresh food for the crew members at Neumayer III. Thus yield (parameter light use efficiency) was ranked first, followed by production (disease resistance) and then quality (taste).

2.4.3 Herbs

As far as the herbs were concerned, aspects were ranked as follows:

Quality > Yield > Production

Within each aspect, parameters were ranked as follows:

Quality: Pungency > Taste = Appearance > Texture
Yield: Light use efficiency > Space/time efficiency > > Harvest Index

Production: Disease Resistance > Spread harvest > Handling time = Shelf life

The results of the plant choice methodology are given in Table 2-4.

Table 2-4. Ranking of herbs.

Ranking No.	Crop	Weighting	Comment
1	Parsley	4.9	
2	Coriander	4.9	
3	Chives	4.5	
4	Basil	4.3	

Within the group “herbs” the rating given in Table 2-4, is due to the relative importance given to the main aspects, with ‘quality’ being the most important. The ranking (order of herbs) differs from that found in the FEG system because there the aspect ‘quality’ was considered to be less important. As far as the ISPR is concerned, herbs can be used according to human needs at that moment, and was not ranked as in the FEG.

3 Cultivar choice within each crop

3.1 List of crops and their cultivars

The following list of crop species and their cultivars are listed in Table 3-1, indicating where their seeds can be ordered from, and if possible, from which source. This list serves as a baseline for further work in WP 2 and WP 4.

Table 3-1. List of crops and their cultivars for use in the FEG and/or the ISPR.

Crop	Cultivar	Facility	Comment
Lettuce	Crispy green cv. Expertise	ISPR FEG	Rijk Zwaan Hydro-cropping. Deep-cut green leafy lettuce, sweet, crispy frisé type.
	Bativia cv. Othilie	ISPR FEG	Rijk Zwaan Strong, hardy leafy lettuce.
	Leaf Lettuce cv. Pulsar	ISPR FEG	Rijk Zwaan Good for year-round production, broad leaves, dark green, very productive.
	Iceberg cv. Morinas	ISPR FEG	Rijk Zwaan
	Iceberg cv. Platinas	ISPR FEG	Rijk Zwaan Very sure of harvest, high harvest percentage. Perfect round shape, well filled and closed.
	Outredgeous	ISPR FEG	Johnny's selected seeds (Massa et al. 2015; NASA) Versatile red romaine for baby leaf production. Solid bright red-colored baby leaf which maintains its color even under low-light conditions. Ruffled leaf margins.
	Rucola cv. Sylvetta	ISPR FEG	Johnny's selected seeds Also known as wild rocket. Compared to salad arugula, Sylvetta is slower growing, about half the height, and has yellow flowers. The leaves are also more deeply lobed with a more pungent flavor.
	Rucola Selvatica-Wild Arugula	ISPR FEG	Growitalian Compared to regular arugula, it is slower growing (50 days), more deeply lobed leaves and has a more pungent taste.
	Rucula Cultivated	ISPR FEG	Growitalian The essential salad spike. Nutty, spicy slightly peppery.
Dwarf tomato*	Mohamed	FEG	Tatiana's TOMTOTbase
	Sub-Arctic Plenty, determinate	FEG	Urban Farmer The Sub-Arctic Plenty is a great tomato to grow in Northern areas where the season is short.
	Scarlet Sweet	FEG	Totallytomato Strongly branched plants produce many fruits over a long season for continuous harvests.
	Red Robin	FEG	Totallytomato An extra-sweet dwarf, container-grown variety, compact plants 20-30 cm tall.
*Determinate and Indeterminate. Determinate varieties, or bush tomatoes, are shorter (4 feet) and stop growing once fruit sets. All fruit ripens within a 2 week period and then the plant dies.			
Cucumber	Quatro	FEG	Rijk Zwaan

			Smooth uniform fruit, 9-11 cm long. Strong open crop, quick in production, good balance between fruit setting and growth. Very good taste.
	Picowell	FEG	Rijk Zwaan Dark green fruit, ca. 15 cm long. Open generative crop, good shelf life, good under artificial light.
	Northern Pickling	FEG	Johnny's selected seeds Medium green fruits bear early, and set heavily on short, space-saving vines. Fertilize well and pick frequently at a small size to maintain good color and fruit shape.
Bell pepper	Cupid	FEG	Johnny's selected seeds Early, sweet, mini bell. Fruits are blocky to slightly pointed, avg. 2" X 1 3/4", and are particularly sweet when red. Large, well-branched plants protect the fruits from sunscald.
	Time Bomb	FEG	A slightly hot pepper with excellent flavor! Time Bomb is a dark-green to bright-red hot cherry pep-per for pickling. Fruits are globular to pointy, measure 4 cm x 4 cm and are slightly less pungent than Cherry Bomb.
	Yellow Mini	FEG	Gourmet miniature with all the flavor of full sized quality bells. These 5 cm bite sized treats can be stuffed, pickled, canned or eaten fresh as a snack. Plant, ca. 40 cm hoog.
Radish	French breakfast	ISPR FEG	Rijk Zwaan Long-shaped red radish with a white point.
	Rover	ISPR FEG	Johnny's selected seeds Rover is fast and has less of a tendency to produce oval radishes under heat stress than other varieties. The smooth, dark red roots are extremely uniform and at-tractive with crisp, white flesh.
Strawberry	Delician	FEG	ABZ seeds Strawberries with a soft aromatic taste.
	Grandian	FEG	ABZ seeds Large fruits with a deep red color and that produce for several months.
Spinach	Gazelle	ISPR FEG	Rijk Zwaan & Johnny's selected seeds Dark green, rounded leaves, sturdy and strong growing.
	Mandril	ISPR FEG	Rijk Zwaan Ovale leaf shape, strong growing variety.
	Red Kitten	ISPR FEG	Johnny's selected seeds Use for baby leaf production. Uniform, smooth leaves are borne on fairly upright plants.
Swiss chard	Ruby Red	ISPR FEG	Johnny's selected seeds Mild beet flavor. Green leaves with bright reddish pink stems.
Red mustard	Frizzy Lizzy	ISPR FEG	Urban Farmer Unique ruffled cherry purple leaves with serrated lobes. Adds spicy flavor and spunk to salad mixes.
	Mizuna	ISPR FEG	Johnny's selected seeds & Urban Farmer (Massa et al. 2015; NASA) Mild flavor. Fancy, toothed leaves.
Chives	Staro	ISPR	Johnny's selected seeds

		FEG	Heaviest leaf.
	Purly	ISPR FEG	Johnny's selected seeds Versatile, medium-sized leaves. Compared to Staro, Purly has a more upright plant habit with a slightly straighter leaf.
Coriander	Cilantro	ISPR FEG	Urban Farmer Highly aromatic, rich and spicy. This plant is very easy and quick to grow.
Mint	Doublemint	ISPR FEG	Johnny's selected seeds Improved selection of spearmint. Excellent spearmint variety for culinary or medicinal use.
Parsley	Moskrul 2-Verta RZ	ISPR FEG	Rijk Zwaan Grows well indoors, easily harvested, uniform growth.
	Frise Vert Fonce-Rina	ISPR FEG	Rijk Zwaan Dark green and slower growing variety.
Basil	Dolly	ISPR FEG	Johnny's selected seeds High-yielding.
	Genovese	ISPR FEG	Johnny's selected seeds Tall and slow to bolt.

3.2 Basis for using these cultivars

All cultivars are commercially available as indicated in the 'comment' section. A good number of cultivars are readily available from Rijk Zwaan, a European breeding company and research partner for EDEN ISS, located in the Netherlands. Others are available at commercial seed companies located in the US, i.e. Johnny's Selected Seeds or the Urban Farmer (see References).
While a large number of the cultivars have been selected following advice given by plant breeders, a few cultivars have been included as they were used by other space agencies like NASA.

3.3 Results of methodology and or choice: cultivars

In the case that sufficient information on the parameters of each individual cultivar was known, the methodology was used to rank cultivars within a crop species. This actually applies only to lettuce. Other cultivars were chosen from a combination of availability and use in earlier space mission experiments.

Table 3-2. Ranking of cultivars.

Crop	Cultivar	Reason for choice
Lettuce	Crispy green 'Expertise' Batavia 'Othilie' Field lettuce 'Pulsar' Iceberg 'Morinas' Rucola 'Wild Argula' Rucola 'Sylvetta' Lettuce 'Outredgeous'	From Rijk Zwaan, best from methodology Used by NASA
Dwarf tomato	Mohamed Red Robin Scarlet Sweet Sub-Arctic Plenty	
Cucumber	Quatro	Advised by Rijk Zwaan

	Picowell Northern Pickling
Bell pepper	Cupid Time Bomb Yellow mini
Radish	French breakfast Rover
Strawberry	Delician Grandian
Spinach	Gazelle Mandril Red Kitten
Swiss chard	Ruby red
Red mustard	Frizzy Lizzy Mizuna
Chives	Staro Purly
Coriander	Cilantro
Mint	Doublemint
Parsley	Moskrul Frise Vert Fonce-rina
Basil	Dolly Genovese

4 Steps forward

The crops selected in WP 2.2 will be grown in climate rooms in Wageningen (WP 4.2). Initially, growth experiments will be conducted in order to define the optimal light recipes (spectral quality, light duration), as well as optimizing water and nutrient use.
In WP 4.2 specific experiments will be performed under similar conditions (size and constraints) to the ISPR and FEG to test the cultivation and management of (combinations of) the crops. Main features of the experiments will entail the determination of light recipes, optimizing CO_2 dosage in accordance to plant growth rates, and relative humidity and temperature in relation to the light system being used. I/O flow (energy and mass) will be monitored throughout the experiments. A monitoring protocol will be defined to determine whether the crops grow as desired.
The monitoring protocol will be detailed and yet as simple as possible in order to be used by personnel with limited training, particularly for the Antarctic deployment phase. Training will also be provided to the expedition personnel (1 person) from ***DLR*** based on documented cultivation instructions. The training will include the general cultivation processes (from seeding to harvest) for the selected crops, as well as advanced tasks. The training will take place at the facilities in Wageningen.

4.1 Conditions for growth

The conditions under which the plants will be grown will be similar to those used in the FEG system, i.e. 20-22°C during day time (lights on) and 16-18°C during nighttime, 70% RH, a CO_2 concentration of 600 ppm and 300-600 µmol/m^2/s light intensity, with a spectrum containing red, white, blue and far-red wavelengths. A day length of 16 h will be maintained.

4.2 Crop testing trials

Of the larger growing crops, i.e. cucumber, tomato and bell pepper, 2-3 cultivars will be grown and assessed for their growth, growth rate, production and handling efficiency. For the smaller crops, add-ons and herbs at least 1 or 2 cultivars will be cultivated and their growth and production will also be assessed. Based on the results, 2 cultivars for each crop will be selected; one for actual use in the FEG and the remaining cultivar likely functioning as a back-up.

5 References

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