Controlled Environment Systems Laboratory
Guelph, Ontario CANADA
N1G 2W1 Tel. (519) 824-4120
Fax. (519) 767-0755

MELLiSSA

Memorandum of Understanding

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Technology Readiness and Cultural Management Strategies for New MELiSSA Candidate Crops

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Cloutier, G.R., Krick, L., Tsjuita, M.J., Dixon, M.A.
University of Guelph

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Technology Readiness and Cultural Management Strategies for New MELiSSA Candidate Crops

Cloutier, G.R., Krick, L., Tsjuita, M.J., Dixon, M.A.
University of Guelph

1. Introduction

Advanced Life Support (ALS) systems are meant to minimize the enormous expenses associated with the re-supply of life support elements during long term manned space missions. It is now accepted that the coupling of algal, bacterial and higher plant production units will more completely address the dietary needs of crew, while considering the need for stable atmospheric quality, potable water production and waste management in the manned outpost.

The European Space Agency has been involved in research relating to micro-organism based life support (MELiSSA program) and has recently contracted the University of Guelph to participate in research relating to the inclusion of a higher plant component. At present a total of eight higher crops are included in the MELiSSA program candidate list (soybean, wheat, onion, lettuce, spinach, tomato, potato, rice; Poughon, 1997). Research by NASA program members indicates, however, that a more comprehensive and nutritionally complete menu will be required (Salisbury and Clark, 1996).

A NASA workshop, entitled 'Human Nutrition in Controlled Ecological Life Support Systems' was hosted in 1996 and resulted in a preliminary list of some 45 candidate crops. These crops were selected for their yield potential, nutritional value, and psychological value and represent a consensus of scientists and engineers specializing in food production, food processing and human nutrition (JSC Memo EC3-96-130). This preliminary list was recently re-evaluated by NASA researchers in the context of the limited resources, budgets and schedules of their program. The group was instructed to focus on a narrower set of crops so that there will be a maximization of the degree to which the technological readiness level (TRL) of each crop is improved (JSC Memo EC3-98-066). As a result of these constraints, the NASA ALS program will focus on crops suitable for both vehicle and planetary food systems including dry bean, rice, sweet-potato, peanut, wheat, white potato and soybean. An evaluation of the NASA strategy in candidate crop selection has led our own researchers to the conclusion that a broader array of candidate crops should be considered regardless of their current TRL. This modified approach confers a greater ability to address dietary needs, while considering cultural compatibility, air revitalization capacity and production scheduling of biomass production units. Eleven crops including kale, carrot, peanut, sweet potato, chick pea, cow pea, lima bean, snap bean/dry bean, garden pea, lentil and broccoli have been selected for TRL evaluation and augmentation of the previous MELiSSA-HPC menu. These new crops have been evaluated through bibliographic review as was done for the eight predecessors of the MELiSSA menu.

2. Selection of Crops for TRL Evaluation

Selection of candidate crops for TRL evaluation was on the basis of four criteria, as defined by the University of Guelph research team:

- Harvest Index - the ratio of dry weights of edible and inedible biomass
- Nutritional Adequacy
- Adaptability to Closed Environment Culture - Cultural Management
- Human Factors - processing, psychological appeal etc.

Much of the preliminary selection of candidate crops was based on personal experience of research team members. The task of the candidate crop evaluation was to fill in details relating to each of the four selection criteria and to assess the crops' suitability for inclusion in the MELiSSA-HPC menu. The current candidate list is presented in Table 1.

Grains	Starchy Roots and Tubers
Wheat*	Sweet Potato
Rice*	White Potato*
Green Vegetables	Yellow Vegetables
Broccoli	Carrots
Kale	
Garden Peas	Legumes
Lettuce*	Peanut
Spinach*	Soybean*
	Chickpea
Seeds: oil & to eat	Lentil
Peanut	White Bean
Soybean*	
Fruits	Condiments
Tomatoes*	Onion*

Table 1. Current MELiSSA-HPC candidate crops. * Indicates that crops were evaluated in TN 40.1

3. Crop Technological Readiness Level

The University of Guelph group has developed a Technological Readiness Level (TRL) scale based on the progression in research needed to achieve optimal production in a closed HPC. These TRL scales are designed to provide a metric by which candidate crops could be assessed for their readiness to be included in a complete ALS system and by which research agenda can be formulated. The TRL scales established by Eckhart (1994) for assessment and identification of flight ready hardware and the generalized crop readiness categories of NASA (JSC Memo EC-98-066) have been considered in the creation of this candidate crop TRL scale. It is important to note that progression and advancement of crops into successive TRL levels may not be linear, since time and budgetary constraints can have a profound impact on the limits of tolerance (i.e. when a crop is ready to proceed to the next research phase). It is also important to note that this TRL metric will be continuously modified as ALS engineers re-define operational and design criteria.

TRL	Type of Research	Research Focus	Planetary Food System Crop
1	Demonstration of basic production concepts	Bfield testing Byield and harvest index determinations Bnutritional value and adequacy Bplant structure considerations	Cgarden pea Cchick pea Clentil Clima bean Csnap bean/dry bean
2	Demonstration of Basic Controlled Environment Production Feasibility	Bhydroponic production possible Bidentification of adequate temperature, PPF, CO_2, ranges for growth Bestimate yield for controlled environment	Ccow pea Ckale ÷onion
3	Quantification, modeling, and optimization of crop response	Bdose-response relationships for CO_2 and PPF, nutrients Bphotoperiod response Bphotomorphogenic responses Bgenetic and cultivar selection Byield optimization	÷lettuce ÷potato ÷rice ÷soybean ÷spinach ÷tomato ÷wheat
4	Studies of Cultural Compatibility	Bdetermine crop performance in the presence of other crops Bstabilize atmospheric conditions Bsimultaneously maintain various crop-specific conditions	
5	Integration Trials	Bcompatibility with other biomass production units and MELiSSA loop	
6	Ready for Flight validation		

Table 2. Results of Candidate Crop TRL Assessment. Crops marked with a '÷' were evaluated in TN 40.1.

4. Crop Specific Cultural Requirements

The basic physiology of plant culture was discussed in TN 40.1 and the MELiSSA Annual report of 1997. Consideration has been given in the definition of plant cultural requirements to CO_2 concentration, light intensity (PPF), photoperiod, day and night temperature, and nutrient supply. For many of the newly evaluated candidate crops, specific information on cultural management strategies for closed environments could not be found in the literature and the information presented is the current state of knowledge for these crops. The information presented in Table 3 forms the basis of the assignment of TRL estimates presented in Table 2.

Crop	**CO_2 (FL/L)**	**Light Intensity (Fmolm^{-2} s^{-1})**	**Photoperiod (hours of daylight)**	**Temperature (day/night) EC**	**Nutrient Supply**
Broccoli *Brassica oleracea*	—	>350	—	<9 rep.	—
Carrot *Daucus carota*	1000	>350	12-20 for vegetative	<10 rep.; 21/16 veg.	Deep Flow ½ x Hoagland’s
Chick Pea *Cicer arientinum*	—	—	16	26/22	EC < 1.2 mmhos cm^{-1}
Cow Pea *Vigna unguiculata*	—	>350	12	30/25	—
Lentil *Lens culinaris*	—	—	16	15-24 veg. 18-21 ger.	pH 5.5-6.8; EC < 3.0 mmhos cm^{-1}
Lima Bean *Phaseolus lunatis*	—	—	Short Day	13-27	pH 5.5-7.0
Kale *Brassica oleracea* var. acephala	1000	>350	16	20/15	NFT ½ x Hoagland’s
Garden Pea *Pisum sativum*	—	1000	16	23/16	—
Peanut *Arachis hypogaea*	—	>350	12-20	25/25 veg. 30/23 fruit	½ x Hoagland’s
Snap Bean or Dry Bean/White Bean *Phaseolus vulgaris*	600	1000	16	24/20	—
Sweet Potato Ipomea batatas	1000	>350	<14 veg.; > 14 rep.	28/22	NFT ½ Hoagland’s

Table 3. Crop Specific Cultural Management Requirements. Data presented above were compiled from a number of sources. Reported light intensities (PPF) refer to minimum recommended levels. Photoperiods listed as 12-20 indicate that the crop is photoperiod insensitive. Reported thermoperiods and photoperiods followed by veg., rep., or fruit refer to recommended periods for vegetative, reproductive (floral induction) or fruiting stages of growth. Nutrient supply is based on hydroponics delivery. NFT=Nutrient Film Technique, DFT=Deep Flow Technique. See TN 40.1 for the composition of a ½ modified Hoagland’s solution. Dashes indicate that information was not available in the literature.

5. Recommendations for Further Study

Evaluation of the candidate crop TRLs indicates that many suitable species for inclusion in the MELiSSA-HPC program are not yet ready for integration into a complete ALS. Improvements in candidate crop TRL may be accomplished through an independent collection of relevant data. In particular, crops with a TRL below 3 require basic closed environment production trials in situations where key environment variables can be controlled. A series of factorial designs can be used to demonstrate feasibility while determining an initial set of cultural strategies. Crops with TRLs equal to or greater than 3 would benefit from intensive quantification and modeling studies in which CO_2 and light response curves can be generated. Such studies lend themselves to a determination of optimal cultural conditions and can be easily accomplished at the individual plant or canopy level using small sealed environment chambers.

While much of the information required for optimization of yield of the proposed candidate crops is not yet available, it is suggested that these crops comprise a portion of the MELiSSA menu. The inclusion of legumes in the menu lends itself to interesting studies relating to atmospheric nitrogen fixation. Further, it is proposed that research relating to sweet potato and peanut production be limited in the University of Guelph program since there activity by NASA and its affiliated research institutions in these areas (Morley, et al. 1999). It is also proposed that the development of dose-response models for three crops be the subject of coming research activities in the ESA-MELiSSA program. Our group is confident, then, that a good proportion of these crops can and will be included in the finalized MELiSSA menu.

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