PeaPod - Testing Plan and Hazard Analysis and Critical Control Points (HACCP) Plan

NASA/CSA Deep Space Food Challenge Phase 2

Jayden Lefebvre - Founder, Lead Engineer
Port Hope, ON, Canada

Nathan Chareunsouk - Design Lead
Toronto, ON, Canada

Navin Vanderwert - Design Engineer
BASc Engineering Science (Anticipated 2024), University of Toronto, Toronto, ON, Canada

Jonas Marshall - Electronics Engineer
BASc Computer Engineering (Anticipated 2024), Queen's University, Kingston, ON, Canada

Primary Contact Email: contact@peapodtech.com

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1 Testing Plan

1.1 Acceptability of Outputs

1.1.1 Testing Procedure

Tested via blind studies where participants are divided into two groups and given either control outputs (i.e. established commercial product) or test outputs (i.e. produced by PeaPod). Participants will rate outputs on 4 criteria (appearance, aroma, flavour, and texture) on a 9-point scale.

To simulate acceptability over a long period of time, it will be important to study outputs with consideration for how the subjects will interact with them. This includes varying preparation methods (fresh, cooked, dehydrated, etc.) and preparing combinations of foods both purely with PeaPod outputs and with external foods that would be available in the field.

Blind studies are eminent in consumer testing as they allow researchers to get a completely unbiased dataset. Special care needs to be taken when presenting, preparing, and collecting samples for testing to ensure researchers do not influence results. Ideally, resources will permit a double-blind study where researchers hire an outside entity to conduct the test and return results with generic labels.

The 9-point scale originates from U.S. Army testing, where it was developed using language which has roughly equal psychological distances between points on the scale. While the use of 9 points is otherwise arbitrary, there exists a large history of research validating its analytical use in long-term food production.

1.1.2 Sample Collection Schedule

1.2 Safety of Process and Outputs

1.2.1 Testing Procedure

Given the environment in which PeaPod will operate, process safety will be developed on the foundation of prevention. This is because crisis response and containment is severely limited in the confines of space: identification often requires propagation of the threat, and quarantine is more difficult and loses a larger proportion of food than it does on earth.

This begins pre-flight, as all materials—especially biological—are sanitized, tested, and packaged in isolation so a breach contaminates as little product as possible. Once everything is installed in the field, the design principles of the entire system take over as methods of preveniton. By using DfX such as minimal testing and minimal interaction, PeaPod minimizes the introdcution of foreign substances and, in turn, the ingress of potential threats. Interaction will only occur at times of harvest and planting, and double as times of cleaning and sanitaion. Using established space station procedures, subjects will harvest and clean product, clean all surfaces, sanitize all surfaces, and plant surface-sterilized seeds.

As for non-biological threats such as heavy metals or other toxins, careful selection and sourcing of construction materials will eliminate most threats to the system. As a regular maintenance measure, flushing of the water and air supplies through the space station's recycling system will prevent buildup by keeping them up to external standards.

Chemical Hazards
As part of PeaPod's DfX regarding prevention, all sourcing of parts and resources has been done with inherent, chemical threats in mind. As a result, the default construction of the unit poses no threat for chemicals or other toxins to enter the biological system or its surroundings.

The other source of potential threats is during crew interaction steps when they harvest, clean, sanitize, and plant. To protect against hazards, PeaPod's maintenance steps follow carefully designed HACCP protocols and use food-safe cleansers and sanitizers.

Biological Hazards
Aerobic Plate Count (APC) testing to be done with the Conventional Plate Count Method outlined in the FDA's BAM Chapter 3: Aerobic Plate Count. This is selected over the Spiral Plate Method as it is inexpensive and uses many household materials. The goal of APC testing is to indicate the bacterial population in food-adjacent sections of the design. Results to be compared against STD-3001 to ensure a maximum of 3000 colony forming units/square ft. Plate count to be minimized by following !CITE (surface cleaning standards? hard to find).

ATP testing to be done using !CITE (lots of stuff about methods but no standards? look at requirements more)

Food Outputs

APC testing conducted on samples as outlined above to ensure bacterial population below 20 000 CFU/g per STD-3001. Testing for enterobacteriaceae will be performed using the MicroSnap EB rapid test to ensure its population is below 100 CFU/g per STD-3001. Testing for salmonella will be performed using a rapid detection kit to ensure a population of 0 CFU/g. Testing for yeasts and molds will be performed with a testing kit to then be analyzed for a population count below 1000 CFU/g.

Critical pathogens to be tested for individually:

- Enterobacteriaceae: 100 CFU/g
- Salmonella: 0 CFU/g
- Yeast and Molds: 1000 CFU/g
- Escherichia Coli: dep. on tech
- Listeria: dep. on tech

By-Product Outputs

1.2.2 Sample Collection Schedule

1.3 Resource Outputs

1.3.1 Testing Procedure

Personally testing nutritional makeup of outputs is far beyond the resources and scope of this project. Instead, a variety of outputs will be produced and shipped to an external, ISO-17025 certified lab such as SGS Canada for testing.

While this is useful for validation on earth, it fails to address the issue of analysis at time of harvest. To tackle this, PeaPod will use data collected on earth-bound trials in combination with lab analysis and existing datasets to develop a way of predicting crop quality during the growing process. By applying algorthmic prediction, we can optimize resource output efficiency by, for example, marking crops that show early signs of failure for replacement. This helps maximize the output to input ratio by cutting losses earlier and with less labour cost than people would be able to.

1.3.2 Sample Collection Schedule

The number of days required for sample collection is entirely dependent on what sample is being produced. For one-time growth products, such as carrots or lettuce, the days required is exactly the time to harvest of the plant. Size of collection is dependent on how many units are run at the same time. For plants that produce products multiple times, such as beans or tomatoes, samples should be collected after each production cycle. This means the time required to collect n samples is C + n*X, where C is the initial growth period of the plant and X the time between harvests. It is important to collect multiple subsequent harvests in order to see the relationship between this and produce quality.

Packaging and shipping will be done according to freight standards of the carrier being used, such as this guide from FedEx.

1.4 Reliability and Stability of Outputs

1.4.1 Testing Procedure

PeaPod's outputs are intended for consumption as soon as possible after harvest and preparation. Any product not immediately consumed post preparation should be stored in an airtight package and kept below 12.5°C to slow bacterial growth. Certain products of PeaPod have the possibility of being dehydrated to further increase their shelf life. To mitigate the need for long duration food storage, growth cycles should be staggered to periodically supply fresh produce when astronauts are ready to eat.(Look into dehydrating processes and shi)

1.4.2 Sample Collection Schedule

1.5 Additional Comments

1.6 Materials

1.6.1 System

Automation

Housing

Aeroponics

Leaf-Zone Thermoregulation

Humidification

Dehumidification

Gas Composition Regulation and Exchange

Lighting

1.6.2 Inputs

Supply Inputs

- *Water*: reverse-osmosis, ambient
- *Power*: 120V 60Hz AC[1]
- *Network*: ethernet or wireless, optional

Consumable Inputs

- *Nutrient/pH Adjusment Solutions*: pouches
- *Dehumidification Cartridge*: recharged

1.6.3 Outputs

Food Outputs

By-Products & Waste

[1]The power supply can be altered to suit a variety of power inputs (i.e. DC)

1.6.4 Maintenance

Spare Components

Tools

1.6.5 Cleaning

Soaps

Disinfectants

Tools

2 Hazard Analysis and Critical Control Point (HACCP) Plan

2.1 Food Production System Description

PeaPod uses automated control systems to generate desired environments. These are air thermoregulation, humidity control, LED lighting, and an aeroponics system. They are automated by an onboard computer and housed in a "control module" at the top of the unit. This lets power be "multiplied" for extended PeaPods by adding more control modules in a controller-follower topology.

PeaPod is an automated plant growth environment, comprised of several control systems regulated by an automation and monitoring system within a modular, cubic housing. It can generate any desired environment while collecting data on plant growth and improving yields. Due to the wide range of actuation for each control system's environment parameter, and the extendable housing topology, the growth environment is adaptable to any plant or mission requirements. In addition, plant growth support platforms (with watering system) and lighting systems are built on modular "trays" mounted to the inside of the housing so the user can position plants and lights to accommodate any plant size.

PeaPod's control systems are made of environmental controls (feedback loops with sensors) and plant inputs (set-states):

- *Lighting*: A wide spectrum of LEDs, from IR to UV, with a focus on Photosynthetically Active Radiation (PAR). Dimmable LED drivers enable precision spectrum and intensity control. Efficient, precise emission spectrum, low heat.
- *Aeroponics*: Reverse osmosis (RO) water is pressurized by a pump (with sensor for safety cutoff), brought to temperature, nutrient-dosed and pH-balanced by custom peristaltic pumps (allows for accurate dosing, and prevents backflow under pressure), and forced through nozzles to generate mist. Root zone air temperature is regulated in the same way as the leaf zone system. Exceptions include an aluminum water block (vs internal heat sink and fan) and a single temperature sensor after the block for PID feedback in a flowing system. Runoff water is recycled. Water-efficient (98% less water use than farming), nutrient-efficient (60% less use than farming), no pH/nutrient "feedback" loop or waste water (common in hydroponics), increased root oxygenation.
- *Leaf-Zone Thermoregulation*: Leaf zone air temperature is regulated by a thermoelectric heat pump. Fans blow air over heat sinks connected to either face of a Peltier tile to circulate air and dissipate heat. A Proportionate-Integral-Derivative (PID) control system is informed by temperature sensors, and controls the direction and magnitude of the heat transfer. Low complexity, high safety/reliability, easy to automate (bidirectional, precisely dimmable, PID tuning).
- *Humidity Regulation*: Leaf zone humidity is regulated by a dead-zone bang-bang control system informed by humidity sensors.
  - *Humidification*: RO water is supplied to a tank with a fine mesh piezoelectric disc. A controllable driver circuit oscillates the disk, producing water vapour. Easy to automate.
  - *Dehumidification*: A dry silica gel bead cartridge is covered by servo-actuated "shutters"

to control dehumidification. Fans draw humid air through a HEPA filter into the desiccant and back into the growth environment on demand. The beads change color to indicate water saturation. The crew is then notified to swap and "recharge" via evaporation in a standard oven.

- *Gas Composition Regulation and Exchange*: Oxygen and carbon dioxide levels are managed by gas exchange. Input and output ports allow fans to draw air into and out of the system. HEPA filters remove microbes and aerosols, and servo-actuated "shutters" prevent unintended exchange. Gas concentration sensors inform a bang-bang control system for port activation.

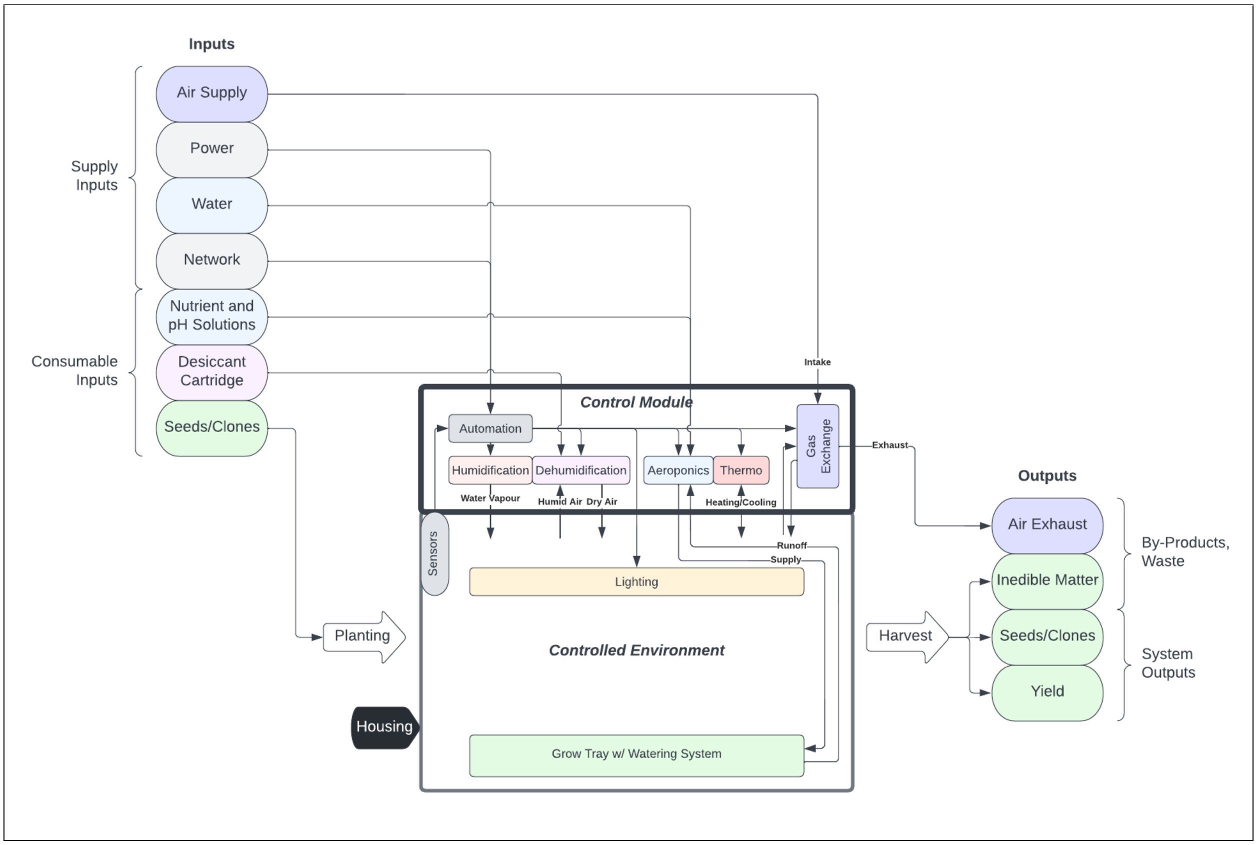

Figure 1: System overview.

2.2 Critical Points

2.2.1 Critical Point A

Hazard Description

Critical Limits

Monitoring Procedures

Deviation Procedures

Associated Documents

2.3 Standard Test Record

2.3.1 Purpose and Summary

2.3.2 Safety and Quality

2.3.3 Test Processes

Preparation of Inputs

Verification

Setup, Maintenance, and Collection Protocols

Storage

Cleanup and Turnover

2.3.4 Closeout

3 Feedback

References