BRIDGING EARTH AND THE COSMOS WITH SUSTAINABLE AGRICULTURE

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Executive Summary

This project, Ahchakosak, envisions self-sustaining agriculture incorporating aeroponic systems, bioreactor technology, and genetic engineering to optimize crop yield. A core innovation would be the automated resource management system, which uses state-of-the-art electrostatic misting technology to ensure efficient nutrient delivery, even within low-gravity conditions. These systems are trained on Earth for two years before deployment to ensure adaptability and resilience. The module is powered by flexible solar panels, supported by lithium-ion batteries and compact fuel cells for an uninterrupted energy supply. Waste treatment is integrated into the system, using microbial bioreactors to convert organic waste into biofertilizers and biogas, recycled into the ecosystem. The agricultural settlement will host over a thousand individuals, which is the minimum genetic diversity requirement. It will have a farming area of two thousand square meters to provide nutritional and healthy food for these individuals, which will be more than enough for the population as we use highly storage-efficient resources. This settlement will be created over 20 years; within the first 5 years, raw materials and the construction process will have started; within 15 years, the construction process will have been completed, and once the 18-year checkpoint has been hit, specialists will have settled. Within the following 2 years, 800 individuals will have settled in, and the settlement will be ready to use. The settlement location will be Phobos, a moon orbiting Mars.

Generative AI was used to generate images and diagrams to understand concepts.

Automated Resource Management

Maintaining an optimal growth environment for our agricultural model is crucial in our space settlement. To do this, we plan on creating an advanced environmental sensor and regulation system that monitors and detects humidity temperature changes to ensure they are regulated in real-time. The ecological regulation system will be trained on data for up to two years before implementation in space to sufficiently train the algorithm within any scenario and prevent possible hiccups. The system will have a temperature range of 18–24°C (65–75°F) for plant cultivation, while bioreactors supporting microbial and fungal growth will be maintained between 20–40°C (68–104°F).

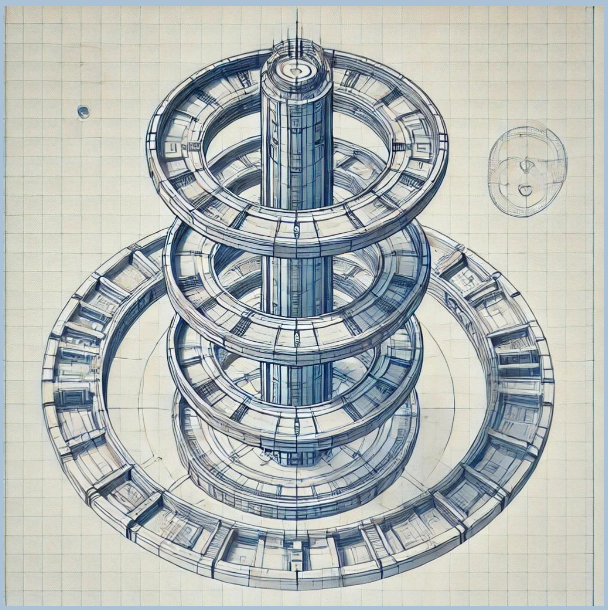

Figure 1: Sketch of blueprint (AI generated)

Our mock-up features an Arduino-based management system programmed to keep a relative humidity of 65-75%, ideal for plant growth. Our model is coded into the Arduino; digital sensors constantly show every change in humidity to lower or higher values; simultaneously, the Arduino can simulate how many accurate adjustments it would have to make for moisture levels to remain consistent. In our mockups, the algorithm within Arduino code initiates the misting nozzles when the humidity drops below the set threshold. There would be a uniform distribution of nutrient-rich droplets on the plant surfaces with nozzles designed for electrostatic technology, thus optimizing absorption while avoiding problems like oversaturation or other nutrient imbalances. Electrostatic misting is very useful in low-gravity conditions where water distribution is challenging.

The Arduino code for environmental control (Appendix A.1) simulates monitoring and adjustment for temperature and humidity in the aeroponic system.

Energy Sources

The infrastructure is powered by a mix of renewable and efficient energy sources built to last in space. Flexible solar panels on the spacecraft's exterior serve as its primary energy source, and intelligent reflectors increase their effectiveness by absorbing as much sunlight as possible. Excess energy is stored in lithium-ion batteries to guarantee continuous operation during low solar access, like lunar eclipses. As a dependable backup, compact fuel cells guarantee that vital parts like pumps, sensors, and illumination always function. Light intensity will be managed using LED lights, which will be adjusted according to the plant and cycle length desired. This will be centralized so that it can be modified as needed.

Moreover, the Arduino system prioritizes critical operations like misting and filtration during low-energy times by constantly modifying the energy flow to improve energy use. This makes the system durable and efficient.

Waste Treatment

The bioreactor component supports a closed-loop system by turning organic waste into valuable resources. A microbial bioreactor converts organic waste from plant matter and human activities into solid biofertilizers and biogas. The biogas is gathered and used as an extra energy source in additional systems like fuel cells and thermal regulation devices. The processed biofertilizers are reincorporated into the aeroponic system's nutrient solution to improve crop development without outside inputs. Thanks to this sustainable strategy, the settlement's resource efficiency increases, and waste is reduced.

Scalability

Given that the infrastructure is built for scalable expansion, enclosed aeroponic chambers can be replicated and positioned vertically or horizontally to make the most of the available area. System reliability is ensured since every part functions independently, meaning that malfunctions in one do not affect others. Real-time data analysis and maintenance are simplified with centralized monitoring driven by AI, which organizes operations across every part.

Genetic Engineering for Crops

Genetic engineering will be essential to improving crop resilience and productivity in space. Introducing genes from radiation-resistant organisms, such as Deinococcus Radiodurans, a bacterium that is extremely resistant to radiation. Crops could be made more resistant to high radiation levels by transferring the genes from D. Radiudurans, which are involved in DNA repair and antioxidant production. This would improve the crops' chances of surviving in space. The second genetic alteration that will be used is gravitropism. This will allow the plant to sense gravity and adjust its development accordingly. This would be used to alter the genes that control the direction of the plant's growth. For instance, improving the PIN-FORMED family of auxin transport genes may improve the stability and structure of roots in microgravity.

Other than that, it is extremely important that we have a space habitat that is in a closed ecosystem. This is simply because any infection or disease that may spread through plants can destroy the entire yield in whole. One gene that can help in preventing diseases is resistance genes, most of the time, already in plants that have good resistance to specific pathogens, Like the RPS2 gene within Arabidopsis thaliana that helps with bacterial resistance and RPM1 for fungal resistance, which would protect space crops. Moreover, we can engineer crops in order for them to produce antimicrobial peptides like defensins, which leads to impeding microbial creation and decreasing the need for chemical treatments.

Faster crop production is another big factor in plants in space. Genetic modifications in genes involved in flowering and maturation, like a gene called the FLOWERING LOCUS T gene, which causes early flowering and shortens the growth cycle, are one of the easiest ways of doing it. But engineering photosynthesizing plants that have a C4 photosynthesis pathway, like the C4 photosynthesis pathway found in amazingly efficient photosynthesizers like maize, could actually increase photosynthesis efficiency but also reduce water loss, which is critical in a space environment where resources are finite. The introduction of genes, including the NRT1.1 gene for nitrate transporter or stress-tolerant DREB1 family genes, would allow crops to absorb and utilize water and nutrients effectively under unpredictable environments. Were these changes made, then crops could grow well in space with minimum inputs of resources for maximum yield, sustainability and resilience against the peculiar stresses of space.

Use Omics and Bioinformatics

Regarding space agriculture, omics and bioinformatics combined with CRISPR gene-editing technology create accurate enhancement of crops for resilience in extreme conditions. To start, genomics detects specific genes related to certain traits within plants, including stress tolerance, nutrient efficiency, and rapid growth. Using CRISPR-based modifications is a better way to hone these certain traits for all space challenges like low gravity, high radiation, and limited nutrients. Transcriptomics will provide us with the real-time gene expression profile to identify early signs of stress responses and further fine-tune such regulatory genes by CRISPR technology to get better adaptability. Proteomics identifies important proteins involved in nutrient uptake and metabolic pathways that CRISPR may change to enhance nutrient use and growth efficiency. Metabolomics gauges plant health, stress responses, and nutritional content; it was also used to boost levels of essential nutrients for settlers by using CRISPR technology. The integration of omics data, bioinformatics, and CRISPR technology provides an accurate and versatile methodology in engineering crops toward sustainable space agriculture.

Meal Plan

Meal	Dish	Nutritional Information
Breakfast	**Chia Algae Parfait:** • Chia seeds (2 tbsp soaked in plant-based milk overnight) • Spirulina (1 tsp) mixed with yogurt (1/2 cup) • Fresh berries (1/2 cup) **Whole-Grain Wrap with Avocado Spread:** • Whole-grain tortilla (1 piece) • Avocado mash (2 tbsp) • Microgreens (1/4 cup)	Fiber: 8g Carbs: 50g Calories: 310 kcal Monounsaturated Fats: 8g Omega-3 Fatty Acids: 0.6g Potassium: 450mg

Lunch	**Rainbow Veggie Bowl:** ● Quinoa (1 cup, cooked) ● Red cabbage (shredded, 1/2 cup) ● Sweet potato (roasted, 1/2 cup) ● Edamame (1/2 cup, shelled) ● Ginger-turmeric vinaigrette (drizzled) **Seaweed Rice Chips (10 pieces):** Made with nori and brown rice flour.	Fibre: 18g Carbs: 80g Calories: 600 kcal Monounsaturated Fats: 5g Omega-3 Fatty Acids: 1.2g Potassium: 900mg
Dinner	**Hearty Mushroom and Lentil Stew:** ● Lentils (1 cup, cooked) ● Mushrooms (1 cup, sliced) ● Celery and carrots (1/2 cup each, diced) ● Spices (thyme, garlic, bay leaf) **Stuffed Bell Peppers:** ● Bell pepper halves (2) filled with millet, chopped spinach, and sunflower seeds (1 tbsp).	Fibre: 10g Carbs: 65g Calories: 550 kcal Monounsaturated Fats: 4g Omega-3 Fatty Acids: 0.3g Potassium: 800mg

Snack	**Air-Popped Amaranth Snack Mix:** ● Popped amaranth (1/2 cup), dried cranberries (1/4 cup), and sunflower seeds (1 tbsp). **Protein Bites (3 pieces):** ● Rolled oats, flaxseed meal, sunflower seed butter, and spirulFibreowder.	Fiber: 14g Carbs: 55g Calories: 320 kcal Monounsaturated Fats: 7g Omega-3 Fatty Acids: 0.5g Potassium: 700mg

Daily Totals:

- **Fiber:** 50g
- **Carbs:** 250g
- **Calories:** 1,780 kcal
- **Monounsaturated Fats:** 24g
- **Omega-3 Fatty Acids:** 2.6g
- **Potassium:** 2,850mg

Positive Effects

Indigenous farming methods like intercropping (e.g., Three Sisters) and the use of hardy crops like quinoa and amaranth offer nutrient-dense space habitat solutions. These methods naturally slow down the breakdown of carbohydrates, increase insulin sensitivity, and control blood sugar levels.

Combining low-GI grains (legumes, millet) with healthy fats (avocados, sunflower seeds) ensures balanced energy release and supports metabolic health.

Potential Risks

Overprocessing crops can reduce essential minerals and fibre even in space, leading to rapid glucose absorption and insulin spikes. A diet that is repetitive with minimal crop diversity may deplete insulin sensitivity and long-term metabolic flexibility, just like in monoculture conditions.

Methods for Improving Insulin Response

Crop Diversity: To improve nutrient variety, rotate indigenous crops such as maize, teff, and amaranth.

Microbial Fermentation: Introduce yeast proteins or fungi to create nutrient-dense, sustainable meal substitutes, drawing inspiration from traditional fermented foods like chicha or injera.

Meal Timing: Adhere to Indigenous eating customs, which strongly emphasize eating balanced meals at various times of the day.

Analysis of Nutrition

Indigenous methods emphasize crops that are high in nutrients and take up little space: Spirulina and other algae provide critical minerals, fatty acids, and protein. Aeroponic greens, such as spinach and kale, provide antioxidants and fibre, but they must be supplemented with native high-protein crops, such as beans or lentils. Aeroponic greens, fermented grains, and algae work together to provide a balanced diet that supports gut health and fullness.

Recommendations for Crop Variety and Supplementation

In space, grains like quinoa, high in fibre, vitamins, and low-GI carbohydrates, offer vital nutrients and aid blood sugar regulation. Bioreactor crops digest proteins and produce vitamin B12, which is frequently lacking in plant-based diets and inspired by Indigenous agricultural wisdom. This method creates nutrient-dense, sustainable food for space missions by fusing traditional food systems with contemporary technology. Resource-efficient bioreactors and fermentation processes in closed-loop ecosystems maximize nutrient output while preserving food independence and self-sufficiency.

Adapted Crops: Utilize genetically modified crops to optimize the amount of vitamins A, D, and B12 essential for space health while addressing the lack of sunshine.

Minimal Techniques for Processing

Motivated by native methods of food preservation (such as sun-drying and grinding), powdered algae uses little energy to preserve nutrients. Blended veggie cakes are also well-balanced meals made with steam-cooked mixtures of protein-rich seeds and aeroponic greens.

Bioreactors' Function in Sustainability Inspired by Indigenous Cultures

Bioreactors recycle biological waste into crop nutrients. This stimulates closed-loop ecosystems in Indigenous agricultural systems. In addition, they can substitute proteins with fungus, such as “space tofu.” They can also create essential amino acids and vitamins (like B12) for healthy muscles. This is inspired by age-old techniques such as making sourdough or miso; microbial fermentation can enhance flavour.

Three Sisters Method

The traditional Indigenous farming technique known as the "Three Sisters Method" focuses on sustainability and balance by growing maize, beans, and squash together in a mutually beneficial system. Although corn naturally supports beans, beans also enrich the soil by fixing nitrogen, benefiting all crops. Squash has large leaves that cover the soil, preserving moisture, suppressing weeds, and enhancing soil quality. Furthermore, this integrated system reduces the dependency on artificial fertilizers. It yields a well-rounded, nutrient-dense diet consisting of fiber and vitamins from squash, protein from beans, and carbohydrates from maize. The Three Sisters principles offer an ideal blueprint for self-sustaining ecosystems in space farming that maximize the sustainability and efficiency of resources. Nitrogen-fixing bacteria can replace beans, while vertical farming can optimize growth in limited spaces. Bioengineering crops similar to squash can provide the necessary nutrients for space travellers by incorporating additional vitamins such as vitamin D. By honouring Indigenous knowledge and integrating advanced technologies, this approach ensures a diverse and culturally significant food source for future space expeditions. The Three Sisters Method combines traditional expertise with modern science to create a sustainable food production concept suitable for space's challenging conditions.

Appendices

Appendix A.1

This Arduino code monitors and adjusts temperature and humidity for the aeroponic system. The code uses simulated sensor readings and mock functions to demonstrate environmental adjustments using a misting nozzle and temperature control.

https://drive.google.com/file/d/1k1XVPhuHgHdedTh8ug_PNIU2kTZ_siWF/view

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