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VEGANAUT SPACE NUTRITION: ADVANCED BIOSYSTEMS AND STRATEGIES TO ENABLE PLANT-BASED DIETS FOR SUSTAINABLE SPACE EXPLORATION

Abstract

Ensuring a sustainable and nutritionally complete diet in space is a critical challenge for long-duration crewed missions. Conventional approaches relying on pre-packaged meals present limitations in nutritional stability, variety, and psychological well-being. Moreover, relying on terrestrial resources is not cost-efficient and imposes technical constraints to implement Bioregenerative Life-Support Systems (BLSS). The cultivation of plants and algae in space can provide a source of nutrition and atmosphere regeneration while reducing the reliance on resupply missions. Therefore, VEGANAUT introduces a plant-based space nutrition methodology with dietary strategies and an operational protocol for a six-person crew. To achieve that, two biosystems are proposed: the Veganaut Hydroponic Rack System (VHRS) and the Veganaut Algae Rack System (VARS). The VHRS is a hydroponic plant growth module tailored to cultivate a varied range of crops, from leafy greens to fruit vegetables, ensuring a balanced intake of carbohydrates, fiber, vitamins, and minerals. The VARS employs photobioreactors designed for microalgae cultivation, focusing on Spirulina (Arthrospira platensis) and Chlorella (Chlorella pyrenoidosa), to provide essential protein sources, omega-3 fatty acids, and key micronutrients such as vitamin B12, iron, and amino acids. Both consider the use of advanced technologies, such as automated nutrient delivery, controlled aeration, CO2 injection, environmental control and monitoring mechanisms for atmospheric regulation, and LED lighting for optimized photosynthesis. In addition, VEGANAUT combines the use of VEGA, a conversational AI assistant, designed to reduce the complexity of system management and facilitate crew interactions. VEGA enhances operational efficiency by providing real-time diagnostics, task guidance, and decision support based on AI-driven predictive analytics. With that, this study presents a comprehensive analysis of these systems, detailing their structure, functions, biomass and nutrient projections, and integration into BLSS, while exploring their economic feasibility and resource-use assessment. To validate these technologies, a research and training platform for analog astronaut missions is presented, allowing researchers to evaluate plant growth dynamics and systems' performance. The ongoing research focuses on systems integration and expansion requirements from small-scale missions to large-scale settlements, adapting to crew size, resource availability, and mission duration. By transitioning to a plant-based dietary model, VEGANAUT offers a sustainable, scalable, autonomous, and resource-efficient platform for astronaut nutrition and food menus in space. Furthermore, the integration of the VHRS and VARS presents an innovative strategy for reliable platforms with continuous, diverse, and nourishing food sources. This indicates relevant pathways to develop self-sustaining solutions for enhanced crew autonomy and long-term economic sustainability in future interplanetary missions.