SpaceBakery—Sourdough Bread on Planet Mars for Sustainable Innovation on Earth

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ABSTRACT

On May 30, 2020, SpaceX launched its first Falcon 9 rocket crewed mission and, with it, a new era of spaceflight in which low-Earth orbit is commercialized and private vehicles can now ferry people to and from space. According to SpaceX, this is a first step toward reaching the planet Mars and settling the first human colony. Although detailed technical elements are being investigated to reach this goal, the challenges of food supply and production have been left mainly unspoken. With a travel time of approximately 7–9 months, a minimum required stay of 2 years, and a high payload cost, it will be impossible to ship all nutrition from Earth to Mars. To tackle this challenge, Puratos, together with different partners, has launched SpaceBakery, a research project on how to feed the first Martian colonists.

On May 30, 2020, SpaceX launched its first Falcon 9 rocket crewed mission and, with it, a new era of spaceflight in which low-Earth orbit is commercialized and private vehicles can now ferry people to and from space (7). According to SpaceX, this is a first step toward reaching the planet Mars and settling the first human colony at this remote location by 2024 (2). This disruptive idea has been explored by major space agencies, although spread over time due to high risk and investment costs. While detailed technical elements are being investigated on how to reach this goal, the challenges of food supply and production have been left mainly unspoken. With a travel time of approximately 7–9 months, a minimum required stay of 2 years, and a high payload cost, it will be impossible to ship all nutrition from Earth to Mars. To tackle this challenge, Puratos, a global ingredient supplier for bakery, patisserie, and chocolate, together with different partners has launched SpaceBakery, a research project on how to feed the first Martian colonists.

SpaceBakery has been set up around the idea of developing a "closed ecological plant cultivation system and bakery" suitable for a Mars mission concept but designed and engineered for direct equivalent applications on Earth: a closed and self-sustainable modular system that is independent from agricultural land or climate and makes optimal use of resources. The specific objective of the project consortium has direct parallels with the challenges of bioregenerative life-support technologies for space applications. As such, the consortium is also targeting valorization on Earth of developed technologies, as some of the challenges faced are quite similar, although to a different extent, to those faced by future colonies on Mars. In this context, one can think about spillover of solutions, such as tackling water scarcity and extreme climate conditions, efficient nutrient use (both for plants and humans), as well concepts based on food circularity.

Because of the multidisciplinary approach, Puratos is partnering with research institutions (SCK.CEN, Ghent University, and Hasselt University) and technology providers (Urban Crop Solutions, Magics Instruments) to investigate how wheat (and bread) can be produced in controlled environments with minimal use of resources. SpaceBakery is innovative in its in-depth investigation of the entire cycle from seed to bread, with a strong emphasis on circularity and sustainability.

Why Bread?

There are many reasons to not choose bread: wheat has a relatively long life cycle compared with leafy greens, leavening is impacted by the lower gravity of Mars, baking requires a lot of energy, etc. In contrast, and on the positive side, bread is a major staple food that brings (or allows inclusion) essential nutrients into the human diet. Also, bread, in all its forms, has been associated with psychosocial factors as culture, religion, habits, emotions, and memories, which all add to overall health and well-being (5). In current space travel, limited attention is given to these factors, and other meals (liquid, energy dense, etc.) are chosen because of restrictions on weight, space, and zero-gravity cooking abilities (1). When conducting long duration space travel to Mars, however, it is expected that the need and possibility will arise to create meals that feed the first Martian colonists both nutritionally and mentally.

Why Sourdough?

Whereas commercial yeast is the common leavening system used for general breadmaking, the use of sourdough for bread on Mars has been put forward based on its permanent availability and its positive contribution to dough rheology, sensory aspects, shelf life, and functional and nutritional features of baked goods (3). Lactic acid bacteria and wild yeast will leaven the dough during fermentation, and, depending on the microbial strains present, contribute in one way or another to the taste and texture of the baked product. Nutritional features of sourdough bread that have been and are currently being investigated are related to its potential to lower the glycemic index, increase mineral bioavailability, and improve protein digestibility (5). These beneficial aspects are decisive for the choice of applying natural fermentation for the processing of flour into consumable products on Mars.

SpaceBakery—The Target

To develop the ideal bread for settlers on Mars, and at the same time tackle the challenges that come along with the environment, the consortium is focusing on how agronomic conditions im-

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pact grain characteristics as well as that of the derived flour and bread made from it. Microbial populations in the closed atmosphere and within the product (intermediates) are being monitored to understand their interactions under the strict conditions of the closed biosphere to apply optimal microbial populations for the production of sourdough. Processing parameters, as well as adding inclusions of different plant species, will be optimized to obtain bread with excellent sensory quality and nutritional profiles.

SpaceBakery—The Approach

To reach the goals discussed above, under limiting water and nutrient supply constraints, unique atmosphere conditions that differ from those on Earth, and with a target of high circularity, a multidisciplinary approach has been devised to set up a "closed ecological plant cultivation system and bakery."

To engineer the closed loop system, six essential elements have been identified for exploration (Fig. 1): 1) design of the hardware for crop production; 2) modeling of wheat growth under specific conditions in the closed environment; 3) recycling and valorization of plant fibers as a source of nutrients in the form of biochar; 4) identification of beneficial microorganisms to optimize nutrient availability for plants and characterization of microbial communities present in each step of the production cycle; 5) understanding the relationship among the atmosphere microbiome, natural fermentation processes in bread, and selection of a diverse range of crops to create nutritious and tasty bread products; and 6) insect-independent pollination of flowering plants.

The first steps are targeting how to sustainably produce wheat in a controlled, closed environment. To this end, a hydroponic plant production system (FarmFlex, Urban Crop Solutions [https://urbancropsolutions.com]) has been installed to produce wheat with limited use of water by reusing drain water and collecting water vapor, produced by evapotranspiration, from the air. This reduces water use by 95% compared with open field production or by 90% compared with production in traditional greenhouses (Urban Crop Solutions [https://urbancropsolutions.com]).

In hydroponic agriculture, nutrient solutions are added to feed crops. On Earth, these fertilizers are synthetized by energy-intensive processes from the air or extracted from deposits and minerals (6). By the end of 2020, it is estimated that the global demand for major nutrients (N, P_2O_5, K_2O) will reach approximately 201 million tonnes (4). One of the constraints to successfully establishing closed-environment space habitats is the complexity and cost of transporting consumables out of Earth's gravity and across interplanetary space. Therefore, it is economically desirable to use and recycle local resources to sustain a human presence. To succeed in growing plants on Mars, it is essential, therefore, to optimize the use of fertilizers and recycle waste streams as much as possible. Aspects under investigation include mineral leaching from Martian-type volcanic rocks (i.e., basalt) by bacteria and recycling of (plant) waste streams by SCK.CEN and the University of Hasselt, respectively. The ultimate goal is to create an optimal growing environment in which plant, environment, microbiome, substrate, and nutrient supply are all in balance. The plant response will be monitored with sap flow sensors and leaf and stem clips, which, together with additional measurements, will allow the University of Ghent to model a functional–structural plant model that is able to simulate the plant response under different conditions to find the optimum balance between yield and resources used.

With a view beyond the Mars horizon, the consortium is preparing for future research on a wide variety of crops to include in baked goods on Mars. A lot of relevant crops rely on pollination by insects. Becase these are not present on Mars, nanodrone pollinators will be developed that are able to recognize flowers and facilitate pollination of future space crops.

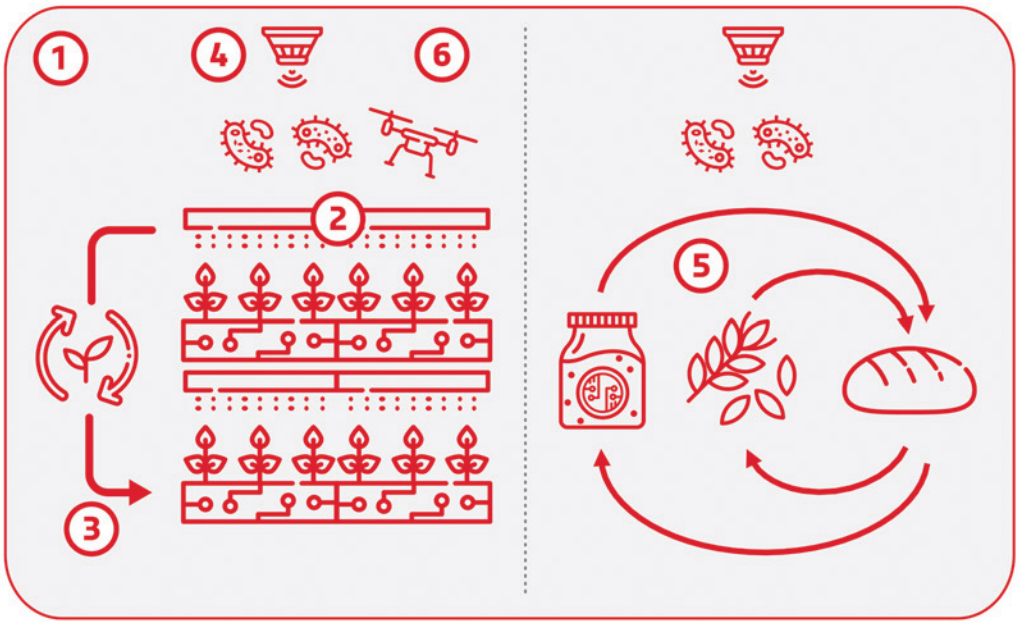

Fig. 1. Schematic overview of the SpaceBakery project: 1) design of hardware for crop production; 2) modeling of wheat growth under specific conditions in the closed environment; 3) recycling and valorization of plant fibers as source of nutrients in the form of biochar; 4) identification of beneficial microorganisms to optimize nutrient availability for plants and characterization of microbial communities present in each step of the production cycle; 5) understanding the relationship among the atmosphere microbiome, natural fermentation processes in bread, and selection of a diverse range of crops to create nutritious and tasty bread products; and 6) insect-independent pollination of flowering plants.

Within a period of two and a half years, the SpaceBakery consortium aims to develop a closed ecological plant cultivation system and bakery that can provide the first Martian colonists with sourdough bread as well as generate insights into sustainable and nutritious food production on Earth. During the past months, many climate movements and the COVID-19 pandemic have made the world more aware and concerned about sustainability and human health and the role of food. Therefore, within this research project, the consortium will also address concerns relevant in domains such as circular food production, bread products focusing on health and well-being, urban farming, robotic pollination, efficient water and nutrient use for agriculture, etc. and, as such, work toward a greener future.

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