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Review Article

Food Production for Mars and Other Hostile Environments - A Universal Sustenance Cell Approach

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Abstract

This article conceptualises a future food system to support life on Mars.

Equally the space food focus has significant overlap with the current global food production system need to adapt and innovate in response to climate change, depletion of natural resources and increasing urbanisation. We explore the many similarities in food security challenges envisaged on Mars and increasingly experienced in the world's megacities - all are hostile environments for food supply and diverse solutions are rooted in the same approach.

Keywords: *Food Production; Mars; Hostile Environments*

Setting the scene

Picture yourself looking out over a barren parched scrubland, littered with drying mud pools, tired sunken trees and withered vines - all baking in the hot sun. Only a generation earlier the scene was teaming with diverse wildlife, rolling fields of grains, grape vines, and other crops, stretching out for as far as the eye could see. When it does rain, it is often in the extreme. Regional flooding can erode the topsoil vital to farming, and has the potential to transport sewage, manure, and other pollutants from the roads onto these tortured lands and muddy drying water ways [1].

Extreme droughts, invasive species, perpetual water shortages and groundwater depletion - all likely to result from the future impact of climate change. These consequences are faced by the U.S corn belt, the California Central Valley, and vast regions in Pakistan, India, north-western China, Iran and Iraq. All are major food producing regions of the world on a trajectory toward this dystopian future.

Without extensive and costly intervention, such regions are likely to become increasingly hostile to food production and eventually degrade to become dust bowls. Dry and desolate places, beaten down by the sun, where only life in its extreme can be sustained and significant food production is ultimately curtailed. These lands cannot sustain meaningful food production, not even scrubland on which cattle can graze. Such places will have an abundance of sunlight and billowing dust storms - remarkably similar in that respect to the conditions one would find on our brother planet Mars, albeit much colder [2].

Before leaving terra firma on a journey to Mars, first let us transport ourselves to one of planet Earth's megacities - New Delhi - which has a metro area population of over 31 million people [3]. A sprawling metropolis with a higher population than the entirety of Australia, Delhi has a heavily subsidised food grain programme which aims to ensure specific foods are supplied every month to eligible households [4]. The city is densely populated, availability of food refrigeration is estimated at only 30% per household, electricity supply is intermittent, and the high temperatures coupled with high relative humidity cause foods to spoil quickly and food safety is an ongoing problem [5]. Pollutants, smog and zoonoses can be found in the land, water and in the air surrounding the city and primary food production is stymied in the regional vicinity. The transport routes are over capacity, dangerous and fragile. Any available space is at a premium and fresh food travels significant distances prior to consumption, often without the benefit of an integrated and consistent cool/chill chain [6].

These megacity environments and challenges are increasingly common. To varying degrees such conditions manifest in most cities across the world. However, with the impact of climate change already being felt, fast forward 25 years and the food supply and security challenges in megacities will have intensified. If not mitigated by a range of interventions the severe repercussions of climate change will certainly be felt by these huge populations [7,8].

A “tragedy of the commons” - due to poor stewardship and irresponsible resource utilisation, major damage to the global climate and resource base has already been done [9]. However, if society and government can now act in a swift, coordinated, and effective manner then the impacts can be lessened and a more sustainable future secured.

Food production, supply and storage is a significant contributor to greenhouse gas emissions across the planet. With climate change likely to hamper our capacity to produce enough food, this is a positive feedback loop of the most negative kind. Therefore, it is evident that food systems need to adjust now, to reduce emissions and solve future production and supply challenges.

As inequalities and malnutrition continue to sweep the world (UNICEF Global Nutrition Report 2020) and yet a third of the global population are classed as obese (Ritchie., *et al*. 2017), traditional approaches to food production and supply are not working. Initiatives to rethink food systems often remain on the drawing board due to numerous socio-economic and geo-political factors.

The food system is not adapting fast enough to the global challenges faced. If the human species is to avoid over half of its global population suffering some form of malnutrition by 2030 urgent action needs to be taken to improve access to high-quality food (EURACTIV, UN Food and Agriculture Organisation (FAO) 2017).

Inspiration is needed alongside global commitment to change. A tangible ambitious vision to inspire change. Away from planet Earth, there is an environment that is as hostile as the places and contexts we have described, where producing food, storing, and distributing it, will be highly challenging and the risk of system failure (food poisoning or famine) to settler populations would be catastrophic.

Let us consider potential food production systems on Mars for inspiration, not as an Earthext, but for an Earthmain - recognising that there are some very similar challenges today and tomorrow both on Earth and Mars.

Building the foundations of a Martian food system

For food production systems to succeed on Mars will require multi-disciplinary science and effective application of outputs into an array of fused technologies to sustain human populations in hostile environments. In many cases such technological solutions will already be in commercial use for applications on Earth and so can be repurposed. A great deal of innovation will be required, and critically innovations will not only need to solve the challenge presented in a safe and consistent manner, but also in the most efficient (ergo sustainable) way possible [10,11].

These multifaceted challenges are an innovator’s liberties and the constraints their aesthetics, as it means that technological solutions do not always have to be ‘high-tech’, instead they must be multi-layered and appropriate, not “over-tech”.

Food production on Mars and in other hostile environments will require a universal system approach; by its very nature all of the required resources are not in abundance, sustaining life - from healthy plants to human life - is fundamental and the tolerance for error is tiny. A universal approach will include all food production inputs, outputs and processes being methodically deconstructed, analysed and challenged against the constraints. Then the constituents are re-assembled into sub-systems and meta-systems, specified, interconnected, monitored and evolved over time - forming a multi-controllable, predictable and ultimately reliable universal system approach to food production and distribution.

A word of caution

The human species often invents things to solve problems - and such inventions can at the same time create problems elsewhere. From a system perspective benefits and disbenefits are to be expected. As previously mentioned, it is not necessarily desirable that 'high-tech' innovations are deployed as the first consideration - as a whole system approach may require less technological dependent solutions.

Assembling innovation teams

This endeavour and its constraints require a diverse range of resources and people who are from multi-disciplinary areas and from multi-contextual backgrounds. A fusion of the best expertise, insight and creativity from practitioners and academics alike drawn from across the globe will be vital. All forming a focused team who can bring their contextual experience, innovative insight, and expertise to develop the technologies and approaches required for this feat of humanity.

The "universal sustenance cell"

A blend of highly advanced science, technologies and biological systems will be required to produce food, sustainably and efficiently in hostile environments. Although a "Universal Sustenance Cell" has not yet been created, we can envisage that the following would serve as key aspects and components of such a multifaceted controlled environment food production system (Figure 1).

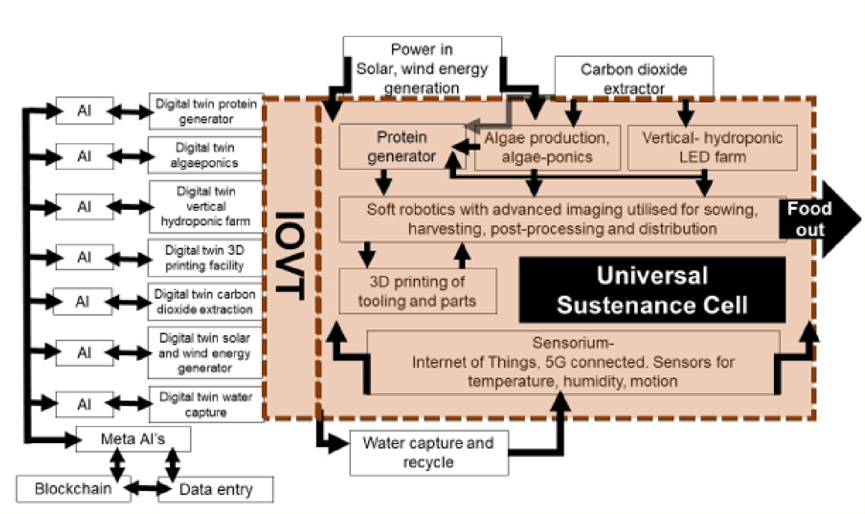

Figure 1: *A schematic of the universal sustenance cell (USC), further detail of the USC components is described in the following text.*

Biological aspects of a universal sustenance cell

Vertical farming (VF): Literally a growing industry across the world, maximising 3D footprint capacity for plant production in a controlled clean environment, with product safety assured via HACCP (Hazard Analysis and Critical Control Point) methodologies. These systems typically utilise hydroponic and LED technologies in their operation.

Hydroponic (incl. aeroponic,) technologies: Hydroponic simply means feeding plants using water/mist, i.e., plants draw their nutrition from the added feed and not soil. Hydroponic systems are typically characterised as either run ebb and flow systems or continuous flow systems. They can be very water efficient, and yields are high. LED technology is readily used, energy consumption can be high, and outbreaks of pests and diseases have the potential to be rapid if not proactively prevented or acted upon swiftly.

Algaeponic technologies (AT): With over 10 times the growth rate compared with terrestrial plants and requiring just a tenth of the landmass to produce equivalent biomass, algae are a sustainable crop source. Algae does not require clean water (and could be used in part to treat water) and being a robust organism would likely be well suited to growth in hostile environments. Algae is a high protein and lipid food source that will certainly have an increasing role in future food systems.

Genetic modification (GM): This technology manipulates the genome of an organism to alter a characteristic in a certain way. Changes could include increasing the nutritional value of a plant or making it more resistant to disease or herbicides. The genomes of the foods we produce can be altered to be more conducive to growth in hostile environments. Modification could be for a wide range of properties including disease and pest resistance, raised yields, improved nutritional content, pharma agents, fuel, natural packaging, ripeness (anti-sense technology), storage/transport resistance, reduction of enzymic browning and many more. The modification may involve one change to the genome or could include many.

Control technology components of a Universal Sustenance Cell

Artificial intelligence (AI): These are computer programs that mimic human intelligence, using logic, "if - then", decision trees. Machine learning and Deep thinking are subsets of AI and permit the AI to learn through the data. Being software applications, AI can run from mobile phone scale equipment. Of all the technological deployments required AI is likely to be the most versatile. Although AI deployments are in a very narrow bandwidth compared to human counterparts, they do vastly exceed human capacity for speed and accuracy. AI would therefore be utilised to identify and maintain (acting and adapting) resource deployments and environmental conditions (e.g. seeds, water, energy, CO_2, sunlight). Benefits will include identification of resource losses/waste and swift progress of corrective actions to avoid/stop/solve/bypass conflicts, ensuring a responsive optimisation approach throughout the whole universal system.

Machine learning (ML): A subset of AI that uses statistical techniques to enable machines to improve at tasks with experience. Repetitious activity is well placed for the application of ML in food production environments including processes such as pick and place robotics supported by integrated vision systems.

Deep thinking (DT): A subset of ML, where algorithms are developed that allow the software to train itself and perform tasks. Examples include the recognition of images, sounds and aromas - incredibly useful across a range of small visual/audio/olfactory tasks. e.g. checking for disease on leaves, detecting olfactory signatures of bacteria and yeasts, identification of pests and control of movements through fusing with advanced imaging technology.

Soft robotics (SR): Mimicking the gentle touch and movement of human hands, an end effector (gripper) at the end of a robot arm is able to pick up and manipulate objects. In hostile environments robots will be easier to maintain compared to their human counterparts. Being mobile, robots can be deployed for a whole host of tasks without requiring a break, food or water. Beneficially hygienic design and cleaning systems will ensure that the robot will not pose a microbiological safety risk to the foods they handle, such as picking fruit, harvesting lettuce or sorting potatoes. Combined with ML, the robotic systems will improve their efficiency and functionality over time and can share those learnings with other robotic applications, making further deployment easier and highly beneficial.

Internet of things (IoT): The technology connects up physical objects - 'things' like sensors, robotics and software - incorporating them into a network. The range of devices assembled allows manipulation and control of the environment and processes. IoT will be very beneficial to deploy due to the array of digital devices required by the universal sustenance cell.

Digital twins (DT): Without the IoT, DT's would not be easy to employ. DT's are representations of processes, products and services in the virtual world. Creating simulacrums of real-world things enables real time monitoring and the capacity to process system data, optimising processes and warding off potential problems.

Internet of virtual things (IoVT): An emerging technology, just as physical things are connected through the IoT, so too are virtual things connected through the IoVT. Virtual sensors base their output and operation on aggregated calculations of one or more underlying physical sensors or alternatively they process data inputs and provide a new interpreted value such as ensuring calibration of devices, e.g. temperature sensors. In totality these virtual sensors help generate new insights to solve resource conflicts.

Automation: Not a new concept, however methods of automation are increasingly incorporating digital components or becoming digital in themselves. Tasks such as the raising and receipt of orders and stock management are good examples of food system deployment.

3D printing: Using reagents to 'print' things, be it tools, components or even food. This "additive manufacturing" technology removes the need to hold vast stores of spare parts, rather the primary material/reagent (such as plastic) is required, and from that an almost infinite array of objects can be made. This can help ensure that food production system downtime is mitigated and the time to obtain and use objects is reduced to demand.

5G: With the high quantity of connected devices through the IoT (and the sheer volume of data traffic), there will be significant demands on the system and a trade off with performance. 5G is 100 times faster than 4G, so there is a substantial increase in performance and also latency (the delay between sending and receiving information). For 4G, the latency is 200 milliseconds, (circa 250 milliseconds for humans to react to visual stimuli). The 5G latency rate is significantly lower at just 1 millisecond.

Virtual reality and augmented reality (AV/AR): The key difference between VR and AR is that AR overlays digital information over the real world, such as displaying a maintenance report over a physical piece of machinery when viewing the machine through a smartphone. Whereas VR is a completely immersive experience. In hostile environments where people are at a premium some aspects may still require human interaction. AV/VR allows a person to have input without physically being there, or at the very least drastically reducing the time required to be present in that physical space.

Renewable power e.g. solar, wind: Obtaining energy from renewable sources to reduce emissions from non-renewable sources will be a vital part of the universal sustenance cell. Not repeating the damaging energy selection mistakes of the past must be a key future aspect of producing food sustainably.

Blockchain: Simply put blockchain is a decentralised, open distributed ledger that records the provenance of a datum. These are effectively lists of records (or blocks) that are linked with hash function - a type of cryptography and in effect immutable. The open, distributed ledger can record transactions between parties, efficiently, securely and in a verifiable and permanent way. With such a significant reliance on digital systems and the repercussions of system failure in hostile environments, security and the need for the 'single truth' offered by blockchain is paramount.

Sensorium: Olfactory, light, temperature, humidity, vibrations, gravity sensors *et al.* this phrase relates to a substantial array of different sensors required to monitor conditions and effects in growing and processing areas. Maintenance including energy, calibration and connectivity are chief concerns, the benefit is that it allows diverse automation and warning systems to be deployed.

LED technology: In recent years there has been major growth in the deployment of light-emitting diode (LED) technology for growing foods. Small LED's are used in an array of colours (or spectrums) which attempt to mimic the light of the sun. LED emitted light affects disease resistance, taste and nutritional levels, as well as yields. The type, duration and distance of light is variable between plant species and so an optimal 'light diet' varies between plants. LEDs last longer, are more powerful and energy efficient compared with other growing lights such as high pressure sodium bulbs.

Video/imaging technology: This rapidly advancing technology is already becoming common place in food production environments. Use includes facial recognition and PPE (personal protective equipment) verification for operator management. Imaging technology enables a wide range of options for product and process monitoring/inspection. Imaging systems can equally be deployed to identify diseases or pest infestation of plants, assess security clearance, ripeness, supporting harvesting and processing of foods (e.g. robot vision systems) and a host of other applications. Ultimately this technology reduces the need for human interaction and promotes automation in many middle functions such as inspection and verification.

Concluding Thoughts

To be ultimately successful there are many other applicable and necessary technologies related to and in subsets of those presented, including computer servers, materials, and reagents. As one of the pinnacles of human endeavour, the heights of current technological capability will provide a foundation for a future universal sustenance cell.

There is a real prospect of humans landing on Mars this century (SpaceX; Elon Musk's stated ambitions) [12-14]. On Earth, farming and food processing in hostile environments, through design, testing and implementation of beneficial approaches and applications, will provide an effective response to climate change and yield food security/sustainability benefits. These actions will also generate many of the technologies and practices necessary to support colonization of our brother planet. A universal sustenance cell is likely to be one of the pre-requisites for humans to secure our future on Earth and at the same time enable us also to become a space faring species.

This is no moon shot, it is an Earth shot with a Mars rebound!

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