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ORIGINAL RESEARCH ARTICLE

SOCIO-ECONOMIC BENEFITS OF MICROGRAVITY RESEARCH

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ABSTRACT
Microgravity researches are conducted in low gravity environments. These low gravity environments can be achieved in a number of ways including parabolic aircraft flights, sounding rockets, drop towers, clinostat. Gravity dominates everything on Earth, from the way life has developed to the way materials interact. The reduction of gravity causes significant changes in the chosen sample which could be cells, plants, micro-organisms and small samples from material sciences. The changes that occur as a result of the effect of microgravity have led to discoveries that have been found to be of socio-economic benefits. Socio-economic benefits involve benefits in wealth, health, economic, environment. Sustainable development in an economy includes economic growth, environmental protection and social equality. Space technology applications such as in microgravity stimulate economic growth and improve the quality of life of people, in this way, it is beneficial to mankind. Overall, products manufactured in microgravity environments have key properties usually surpassing the best terrestrial counterparts. Commercially, these products have attractive features that facilitate marketing. This review considers the various benefits of microgravity research in life-sciences such as in microbiology, pharmacy, and medicine.

1.0 Introduction

Microgravity literally means very little gravity. Scientists do not use the term microgravity to accurately represent millionth of 1g, as 1g is the Earth's gravity. The microgravity environment, expressed by the symbol μg, is defined as an environment where some of the effects of gravity are reduced compared to what is experienced at Earth's surface. Microgravity is generally referred to as a state of weightlessness (Figure 1). Gravity at the Earth's surface is referred to as a one-gravity (1g) environment.

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Figure 1: In microgravity, astronaut Suni Williams could easily move this equipment that weighs more than 700 pounds on Earth. Image Source – Credits: National Aeronautics and Space Administration (NASA) (2012).

Sir Isaac Newton (1642-1727) described gravity as a force that governs motion throughout the universe, not just on Earth. It is the attraction between all masses in the universe. The body is accustomed to a one-gravity (1g) environment and feels different if that gravitational force is changed (NASA, 1997). A gravity-related phenomenon is either directly affected by reduced gravity or becomes significant as the gravity level is reduced (National Research Council, 2000). In general, the focus of microgravity research and applications are in the study and assessment of these biological, physical, and chemical phenomenology and related issues (Jeanne and John, 2015).

Conducting experiments in a microgravity environment has the potential for discoveries that can both improve life on Earth and advance the understanding of space (Jeanne and John, 2015). Actual microgravity environment can be provided for short duration by generating free fall conditions close to the Earth's surface with sounding rockets and airplanes in parabolic flight and drop facilities (Clement and Slenzka, 2006). Orbiting spacecraft provide the best laboratories for long periods of microgravity research. Scientists also use drop towers (Figure 2), aircraft, and rockets to achieve short periods. An important advantage of having longer periods of time available is that scientists have the ability to do research like it is done on Earth. Experiments can be performed multiple times with different parameters (Oluwafemi et al., 2018a). Thus, scientific researchers will be able to gather comprehensive data. The space laboratories such as the International Space Station (ISS) (Figure 3), is such that platform (Oluwafemi et al., 2018a). The space station provides a microgravity environment for researchers to conduct multidisciplinary investigations, for educators to inspire next generation scientists and engineers, and to serve as a stepping stone to future exploration that was not possible just some years ago. The space station has the potential to improve and change lives on Earth with each investigation and technology test that takes place in orbit. With collaboration from the original international partnerships to the insights of inventors and integrators of the research and technology on the ground, there can be anticipation of continued space station benefits for humanity (NASA, 2013).

These all led to the development of several alternative ground-based instruments for simulation of microgravity or elimination of gravity. Clinostat is one of such instruments. Types of clinostat include the two-dimensional (2D) (Figure 4) and three-dimensional (3D) clinostat. To perform experiments using 2D clinostat, possible samples are plants, cells, micro-organisms, fungi and small samples from material sciences, but it cannot accommodate averagely more than 500g of sample. Depending on the sample chosen, there are many factors such as the humidity, temperature and light that need to be maintained at a specific range, while on the clinostat, rotation speed, rotational axis angle and rotation direction depends on the discretion of the experimenter (Oluwafemi et al., 2018a).

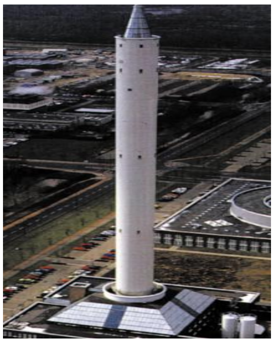

Figure 2: The Drop Tower in Bremen, Germany.
Image Source – Credit: European Space Agency ESA (1998).

Figure 3: The International Space Station (ISS).
Image Source – Credit: NASA Television (https://www.nasa.gov/mission_pages/station/main/index.html)

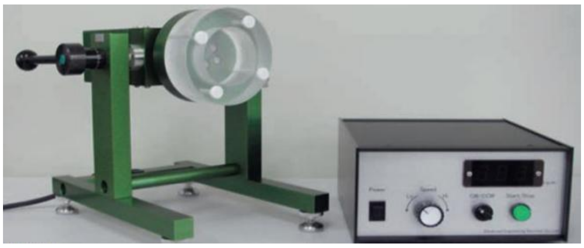

Figure 4: 2D Clinostat.
Image Source – Credit: Microgravity Simulation Laboratory, Engineering and Space Systems Department (ESS), National Space Research and Development Agency (NASRDA), Abuja, Nigeria. Oluwafemi (2018a).

Since spaceflight microgravity experiments are unusual and expensive, this therefore restrict the number of research scientists in this area. Therefore, the use of the microgravity simulations equipment such as clinostat and drop tower has enhanced microgravity research on Earth; as before the advent of the microgravity simulators, spaceflight microgravity experiments are unusual and expensive, this therefore restricted the number of research scientists in this area (Oluwafemi, 2018a). Several researches ranging from physical to life sciences have being conducted under both real and simulated microgravity researches. For example, the principle behind the use of the clinostat as a microgravity simulations equipment is that the centrifugal and the centripetal forces are made equal (United Nations, 2013). Most of the plants grown on the clinostats usually have better growth rates than those grown under normal Earth gravity

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(Oluwafemi et al., 2018b). This is usually determined by measurement of the root lengths of both samples using ImageJ software to analyze the pictures of the plants' seeds taken per time (United Nations, 2013). The data generated can add to the analytical knowledge of the effect of simulated microgravity on the plants experimented upon on Earth which will help for future space experiments and missions on such plants. Since clinostat rotation majorly affects plants growth positively (Oluwafemi et al., 2018b), this will help to increase the productivity in sectors like agriculture for example by isolating the gene for growth from the microgravity simulations sample and inserting them into the wild type of such plant (Oluwafemi et al., 2018b).

Therefore, the focus of this review work is on the benefits of microgravity research in the life sciences. The benefits of microgravity research in the following fields are discussed: Biology, Microbiology, Agriculture, Pharmacy and Medicine.

2. Why Research in Microgravity?

Gravity can be a disrupting factor for scientists, because it may distort the underlying physical processes they attempt to study. It is fundamental for scientists to create microgravity conditions in order to better observe and control phenomena and processes that are normally masked by the effects of gravity, and to perform experiments that would be impossible on the Earth's surface (Mark, 2017).

The reduction of gravity causes significant changes on the chosen samples during experiments. These samples could be plants, cells, micro-organisms and nanoparticles. The changes that occur as a result of the effect of microgravity have led to discoveries that have been found to be of socio-economic benefits. Conducting experiments in a microgravity environment has the potential for discoveries that can both improve life on Earth and advance the understanding of space (Oluwafemi, 2017).

From integrated circuits, to silicon solar cells and memory foam, the benefits of previous ventures into space have transformed the way we live and operate as humans. The promises of this new generation of space exploration are equally vast, offering us the potential for an array of possibilities from the design of more efficient therapies and better vaccines, to creating stronger and more conductive materials, to developing new plant varieties that are better adapted to extreme conditions. The opportunity for advances offers an infinite horizon of possibilities that does not just lead to new products, but to entirely new categories that can fundamentally change the way we live (Jeanne and John, 2015).

Some selected examples of research where microgravity as a tool is relevant for application-oriented and industrial research, in a wide range from physical to life sciences under crystal growth are (ESA, 1998): crystal growth of electronic and photonic materials from the melting or the vapour phase allows to understand the influence of gravity on the crystal growth process and produce benchmark samples which improve the quality and homogeneity of crystals of compounds. This application is found in the high sensitivity X-ray detectors for medical diagnostics (ESA, 1998). Another example is the crystal growth of biological macromolecules that allows to monitor and control the process in order to grow high quality crystals suitable for detailed structure determination which identify the drug inhibiting an active molecule. This application is found in the fast drug design on the basis of the detailed structure of the target molecule (ESA, 1998).

The microgravity environment of space makes it an excellent biological laboratory (Kazuto, 2015). In microgravity environment, scientists conduct experiments that are impossible to perform on Earth, as this environment can serve as biological scaffold (NASA, 2008). Cells, microbes, plants, samples from material science down to macromolecules behave differently in space. Monitoring reactions and processes in the absence of the gravity variable - which can mask subtle observations - can lead to a better understanding of infectious diseases and the human immune response to them. The effect of microgravity on protein crystallization cannot also be over-emphasized in the making of new drugs, since protein structure is key in therapeutics (ESA, 1998). This is because protein structure (primary, secondary, tertiary or quaternary) cannot change under normal Earth gravity, but under microgravity, it can inter-convert to another. New drugs can then be produced as a result of this change in structure of the protein. Structural information gained from protein crystals can provide a better understanding of the role of a given protein in the body's immune system. (ESA, 1998).

Scientists have been studying the effects of microgravity on astronauts in orbit for some time. An example is research on bone and muscle mass while in space (Kazuto, 2015). This has yielded valuable data that can help the diagnosis and treatment of patients suffering from muscle wasting diseases and bone density conditions such as osteoporosis. The ISS is where the best scientists on - and off - Earth are performing these experiments.

Life in the microgravity environment of space brings many changes to the human body. The loss of bone and muscle mass, change in cardiac performance, variation in behavior, and body-wide alterations initiated by a changing nervous system are some of the most apparent and potentially detrimental effects of microgravity. Changes to bone are particularly noticeable because they affect an astronaut's ability to move and walk upon return to Earth's gravity. Some of the processes and functions of bones change after the astronaut has lived in microgravity for several days. In space, the amount of weight that bones must support is reduced to almost zero. At the same time, many bones that aid in movement are no longer subjected to the same stresses that they are subjected to on Earth. Over time, calcium normally stored in the bones is broken down and released into the bloodstream. The high amount of calcium found in astronaut's blood during spaceflight (much higher than on Earth) reflects the decrease in bone density, or bone mass. This drop-in density, known as disuse osteoporosis, leaves bone weak and less able to support the body's weight and movement upon return to Earth, putting the astronaut at a higher risk of fracture. The exact mechanism that causes the loss of calcium in microgravity is unknown (Shelley and Brian, 2009).

Many scientists believe that microgravity somehow causes bone to break down at a much faster rate than it is built up. However, the exact trigger for this rate change has not been found. Multiple lines of research, including hormone level, diet, and exercise, are being done in order to determine exactly what causes, and may control or prevent osteoporosis during space flight. Just

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as astronauts eat a careful diet and get plenty of special exercise in space to prevent disuse osteoporosis, steps can be taken to prevent osteoporosis on Earth (Shelley and Brian, 2009). A balanced diet rich in calcium and vitamin D, exercise, a lifestyle free of smoking and alcohol, bone density testing, and medication all prevent or alleviate osteoporosis (Shelley and Brian, 2009). Astronauts are not the only ones who must worry about bone loss. One and a half million Canadians suffer from osteoporosis, a disease that causes bones to lose density and strength. One in four women and one in eight men over the age of 50 have osteoporosis. Solving the problem of bone loss in space will also help to prevent and cure the disease on Earth (Canadian Space Agency, 2006). Therefore, actual and "simulated" spaceflights, with investigations conducted at whole body and cellular levels, are needed to elucidate pathogeny of bone loss in space, to develop effective countermeasures, and to study recovery processes of bone changes after return to Earth (Zerath, 1998).

3. Socio Economy in Microgravity Research

Prosperity encompasses every good thing of life. It involves wealth, riches, sound-health, affluence, well-being, plenty, ease, luxury, having-speed, fortune, peace, joy, success etc. Hence, economic prosperity in this context means having a sustainable and developed economy. Sustainable development in an economy includes economic growth, environmental protection and social equality. Space technology applications such as in microgravity stimulates economic growth and improves the quality of life of people; therefore, it increases economic prosperity and reduces poverty. In this way, it is beneficial to mankind (Oluwafemi, 2018b).

Space technology has contributed immensely in the drastic transformation of space-faring nations socially, industrially and economically. Most developed and some developing nations like the USA, Russian, UK, Canada, China are well known to be space-pioneering nations. Space technology through its spin offs and by-products has made an impact in every aspect of life, from the economic and industrial development to the mini technologies used for terrestrial applications. Space technology has helped in the improvement of information and communications technology, infrastructure, agriculture, education, all these being the basic factors for a sustainable development (Oluwafemi, 2018b).

Space technology application in economic growth is through these means: new jobs, new markets, increased efficiency, improved competitiveness etc. It also includes through: activities directly related to space products and services (satellites, launch vehicles, ground systems); new capabilities, businesses, products and services derived from space technologies (i.e. spinoffs from the space program); productivity enhancements and quality of life improvements, such as from improved health, enriched baby food and other medical advancing spinoffs (Oluwafemi, 2018b).

Overall products manufactured in microgravity environments have key properties usually surpassing the best terrestrial counterparts. Commercially, these products have attractive features that facilitate marketing (NASA, 1997). These does not just lead to new products but to entirely new categories that can fundamentally change the way we live.

As most of the plants grown under microgravity environment usually have better growth rates than those grown under normal Earth gravity (Oluwafemi et al., 2018b). This can help to increase the productivity in the agriculture sector by isolating the gene for growth from the microgravity sample and inserting them into the wild type of such plant (Oluwafemi et al., 2018b). This makes this microgravity product better than the terrestrial counterpart.

NASA's budget related to microgravity research and development exceed $350 million per year between 2016 and 2017 (NASA, 2017). In 2013, with $314 billion in commercial revenue and government spending, an average annual growth rate between 5% and nearly 8% was recorded (NASA, 2017). This makes the space sector one of the fastest growing sectors in the world.

4. Patents Resulting from Microgravity Research

More than 818 patents have been granted from 1981 to 2012 as related to the subject of microgravity as seen in Figure 5. The use of patents as an indicator of value creation signifies economic potential (Jessica, 2012). Patents are government authority or license conferring a right or title for a set period, especially the sole right to exclude others from making, using, or selling an invention.

The use of patents as an indicator of value creation signifies economic potential. In addition to granted patents in microgravity, additional 580 microgravity applications have filed with the U.S. Patent and Trademark Office during the last decade. From microgravity technologies, there is a prediction of a 21st century revolution in microbiotics that will dramatically change the approach to human health care and food production" (Jessica, 2012).

Developments based on microgravity investigations and exploration creates compelling competition between agencies, scientists and engineers. This includes both research and technology developments, as seen in both cooperative and parallel projects that may lead to benefits for humanity. "The fields of molecular and cellular biotechnology have already demonstrated the competitive advantages of microgravity environments" (Jessica, 2012). The top seven patent categories include the following: biotechnologies (36%), instrumentation/analytical (13%), materials (12%), aerospace components (12%), and systems in the areas of thermal, measurement, and human health (4% each) (Jessica, 2012).

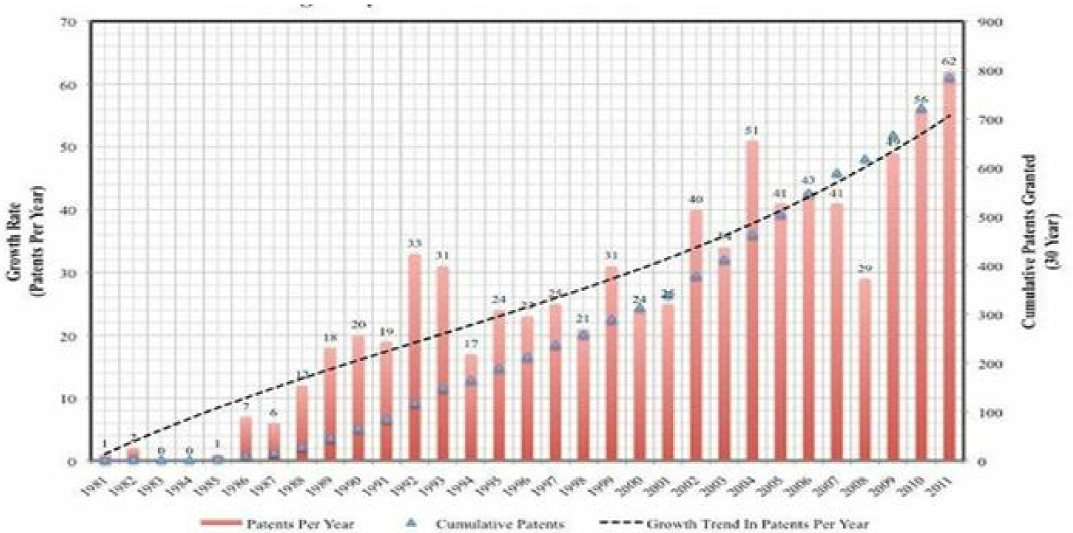

Figure 5: This chart shows the upward trend of microgravity-related patents over 30 years, as related to the International Space Station (ISS). Image Source - Credit: Jessica (2012).

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5. Benefits of Microgravity Research in Life Sciences

Life sciences comprise the fields of science that involve the scientific study of living organisms, such as micro-organisms, plants, animals, and human beings, as well as related considerations like bioethics. While biology remains the center-piece of the life sciences, technological advances in molecular biology and biotechnology have led to a burgeoning of specializations and new, often interdisciplinary fields. Life sciences are helpful in improving the quality and standard of life. It has applications in health, agriculture, medicine, pharmaceutical industry, food science industry (Valenti, 2014).

Influence of gravity on living organisms cannot be under-estimated. Gravity is a fundamental force that has a marked influence on all life on Earth. Life scientists and biomedical researchers exploit the space environment and in particular the near-weightlessness in order to answer fundamental questions in basic biology relating to humans, plants and animals. Various investigations on the response of microgravity on lungs, brain, nervous system, bones and muscles have already been performed. Experiments in microgravity are needed to observe and to determine the influence of gravity on the processing and amplification of signals involved in the gravity sensing and response of cells, cell aggregates and tissue or whole organisms. Any advance in the understanding of these fundamental aspects is important for the future of medical science (ESA, 1998).

So many experiments in space life sciences has been carried out for example by the space life science of National Aeronautics and Space Administration (NASA). Some of them are: NASA researchers are learning new things about the human brain by studying how astronauts regain their balance; flames form tiny almost-invisible balls that might reveal the secrets of combustion here on Earth; taking small columns of sand into space, and returning with valuable lessons for earthquake engineers, farmers and physicists (NASA, 2003).

5.1 Benefits of Microgravity Research in Microbiology

Micro-organisms are living microbes that cannot be seen without an aid of a microscope. They could be unicellular, multicellular, or cellular for example viruses, bacterial cells, bacterial and fungal spores, and lichens. Microbiology encompasses numerous sub-disciplines including virology, mycology, parasitology, and bacteriology. Micro-organisms form biofilm which are mainly antibiotics resistant, this makes them to play essential roles. Space microbiology is the study of microorganism in outer space. Micro-organisms behave differently under microgravity. Spaceflight microbes are great potential for novel therapeutics and vaccine.

The responses of microorganisms to selected factors of space (microgravity, galactic cosmic radiation, solar ultraviolent radiation, and space vacuum) were determined in space and laboratory simulation experiments. In general, microorganisms tend to thrive in the space flight environment in terms of enhanced growth parameters and a demonstrated ability to proliferate in the presence of normally inhibitory levels of antibiotics (Horneck et al., 2010). However, there are some microbes that are beneficial to human health too. For instance, specimens of fungi were found to produce new compounds that could be used for medical purposes. Due to the stress of microgravity, fungi could produce new substances that might be used in cancer treatment. Note that, these microorganisms under normal Earth gravity will not produce such compounds.

5.1.1 Secondary Metabolite Production

Basic research shows that space flight is generally conducive to bacterial growth, it has also been hypothesized that secondary metabolite production of commercial interest might likewise be enhanced. In the first of a series of experiments aimed at characterizing this response, (Lam et al., 1998) showed that monorden production by the fungus *Humicola fuscoatra* was increased when it was cultured on two different solid agar media in space. Interestingly, the increase was attributed to microgravity environment as fungal biomasses were not significantly different between the flight and ground cultures. A follow-up spaceflight experiment similarly showed specific productivity of actinomycin D by Streptomyces plicatus in suspension to be increased as well (Lam et al., 2002). In a related endeavor, Brown et al., 2002 found that E. coli not only reached higher cell concentrations in space (and on clinostat) but also did so without consuming more glucose, suggesting that a more efficient nutrient utilization process accompanied the gains in growth with cost effectiveness. These promising studies culminated in an experiment conducted using an automated fed-batch reactor placed onboard the ISS, which corroborated the findings that actinomycin D production by *Streptomyces plicatus* increased during the first 2 weeks of the mission (Beniot et al., 2006).

Additional ground-based research aimed at evaluating secondary metabolite production has been conducted using the RWV bioreactor microgravity simulation technique (Fang et al., 2000) examined the effect of simulated microgravity on production of rapamycin by *Streptomyces hygroscopicus*. Interestingly, a proportionally greater quantity of rapamycin was extracellularly localized in the simulated microgravity environment, both with and without beads, than under normal gravity conditions (Fang et al., 2000, Gao et al., 2001, Guadarrama et al., 2005).

5.1.2 Vaccine Development

A series of commercially sponsored vaccine development experiments has been performed based on altered microbial virulence in spaceflight. These opportunities, now being carried out aboard the ISS, are part of the National Lab Pathfinder (NLP) missions. The goal of the NLP projects is to develop a vaccine against diarrhea-causing strains of Salmonella, for which no vaccine is currently available. The study is conducted by launching *Salmonella enterica* and *Caenorhabditis elegans* worms in isolated containment, after which they are serially mixed, grown, and fixed in flight. These promising pilot studies suggest potential beneficial commercial applications of enhanced antibiotic production efficiency and novel vaccine development from microbial space research; however, conclusive results from this research are not yet available (Tara, 2019).

5.1.3 Microbial Virulence and Drug Resistance in Space

Beyond the outcomes described above indicating that bacteria generally tend to fare well in space in terms of reduced lag phase, increased population growth, and potentially enhanced secondary metabolite production, other experiments further suggest that the effectiveness of

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antibiotics against microorganisms may be reduced and microbial virulence may be increased (Nickerson et al., 2004).

Leys et al. (2004) reported that significantly greater concentrations of various antibiotics were needed to inhibit in vitro bacterial growth in space. Two somewhat competing hypotheses can be posed to address this observed outcome. Either bacterial resistance is increased in space or overall drug efficacy and/or uptake rate is reduced.

Microbial virulence and drug resistance in space can also plausibly result in visible growth occurring in space (or in a simulated space environment).

5.2 Space Farming and Benefits of Microgravity Research in Agriculture (Crop)

Space farming refers to the cultivation of crops for food and other materials in space or on off-Earth celestial objects – equivalent to agriculture on Earth (Jessika, 2019). Figure 6 shows a concept of a device for growing plant in space. Supply of food to space stations and proposed interplanetary spaceships is staggeringly expensive. Furthermore, the impracticality of resupplying interplanetary missions makes the prospect of growing food inflight appealing. The existence of a space farm would aid the creation of a sustainable environment, as plants can be used to recycle wastewater, generate oxygen ($10m^2$ of crops produces 25% of the daily requirements of 1 person, or about 180-210grams of oxygen, continuously purify the air and recycle faeces on the space station or spaceship. This essentially allows the space farm to turn the spaceship into an artificial ecosystem with a hydrological cycle and nutrient recycling. It can therefore be said that plants can assist the life support system since they can be used to purify water and recycle carbon dioxide into oxygen. When grown on a large-enough scale, plants therefore hugely impact how spacecraft and colonies are designed (Mike, 2017).

Figure 6: Showing Device for Growing Plants in Space.
Image Source – Credit: Jay (2015).

Back here on Earth, the impact of space farming will expand our knowledge of agriculture. There are several spin-offs from ISS research and technology. Monitoring of crop growth for disease and fertility differences are usually done on space farming and Earth crop farming. Farmers are now using cameras aboard the ISS to come up with new and more efficient ways of maintaining their crops.

Researchers hope to transfer what they learn about growing food in the inhospitable climate of space to equally challenging and hostile climates on Earth. They are collecting detailed information about how plants grow and hope this information will help as land becomes scarcer and less fertile. Goals include higher quality crops, higher crop yields and better controlled agricultural systems and greenhouses (Mike, 2017).

Space farming has led to some other surprising and useful applications on Earth. One is a special device called Bio-KES which converts ethylene into CO_2 and water using ultraviolet light. Ethylene causes plants to ripen and eventually spoil. A device like Bio-KES, used in food storage units and display cases, could help increase the shelf life of produce, flowers and other perishable items on Earth (Andrew, 2003).

Another area which could have unexpected consequences involves the study of plants' cell walls. Through space farming, scientists may discover how to control and regulate how sturdy a plant will grow. Some plants might benefit from this research in regards to better weather durability. In addition, trees with less-sturdy cell walls would grow faster and be easier and cheaper to process into paper. These genetically-modified trees could help slow deforestation by becoming reliable, quick-growing resources for paper production (Mike, 2017).

However, nations engaged in space are actively assessing, both qualitatively and quantitatively, the productivity, effectiveness, and Return On Investment (ROI) of these endeavors, given the intense competition for resources and funding for alternate pursuits. With the high costs associated with a space program and the limited resources available, a growing number of states are recognizing the need to identify and provide value back to their societies in order to justify spending on space. India, for example, has found a number of ways to articulate the benefit to their people of improved space capabilities including affordable launch and expanding satellite networks that yield terrestrial benefit through increasing crop yields by providing farmers with greater environmental data, or by mitigating the loses from severe weather from better warning systems (Jeff, 2016).

5.3 Benefits of Microgravity Research in Pharmacy

Space-based pharmaceutical research introduces an opportunity to improve the understanding of how bioprocesses occur by removing the ever-present influence of gravity from a cell and its surrounding environment. This unique research environment opens new horizons for exploring unconventional bioprocessing techniques, perhaps initially for gaining knowledge to be applied in terrestrial production facilities but also for future visions of space-based products with sufficient value added to warrant commercially viable, on-orbit production (Kazuto, 2015).

Biological macromolecules such as proteins, enzymes and viruses play a key role in the complex machinery of life. They possess active sites which make them bind or interact with other molecules in a very specific manner that determines their biological function. They intervene in the regulation, reproduction and maintenance mechanisms of living organisms, and they can be the cause of diseases and disorders. Pharmaceutical drugs are molecules that inhibit the active sites of macromolecules and, in principle, are intended to affect only the targeted macromolecule. The vast majority of current drugs are the result of systematic testing, first at molecular level, then at a clinical level (ESA, 1998).

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This extensive process significantly increases the cost of the product. With a detailed knowledge of the 3D structure of a macromolecule, biochemists can restrict the range of drugs to be tested. Furthermore, with a rational drug design approach, one may attempt to synthesize a drug targeted exclusively on a specific macromolecule. That means a drug will perfectly bind to the macromolecule and inhibit its biological function while remaining inert viz-a-viz other macromolecules (ESA, 1998).

The 3D structure of the macromolecule can be discovered through the analysis of crystals by X-ray diffraction: the diffraction pattern maps the structure of the molecules in the crystal. High quality crystals lead to fast determination of accurate structure which leads to faster identification of drug. Controlled crystallization requires a multi parameter approach. Gravity-dependent parameters that may affect crystallizations include sedimentation, convection and consequently nutrient transport rate and wall contacts (Kazuto, 2015).

Research efforts in laboratories aim to control the conditions in order to favor the nucleation of a small number of crystals and, subsequently, steady growth to large sizes and crystallographic perfection. Crystals of photosystem grown in space had a 10 to 20 times larger volume than those grown on the ground and allowed the refinement of the structure from 4 Å to 3.4 Å. Space crystals of collagenase diffracted with a higher intensity compared with their ground counterparts, and allowed a further refinement of the structure. Under otherwise identical conditions in space, fewer but larger thaumatin crystals were obtained with a measurably higher internal order (ESA, 1998).

Comparable improvements in crystallization under microgravity have been reported in the scientific literature for about 20% of the macromolecules tested. It is likely that the growth of many crystals could be conducted more successfully in space. Current efforts toward understanding and controlling the various mechanisms involved in the overall process should continue, and a well-defined and documented experiment in microgravity will also help to learn to control and optimize conditions, leading to better crystals. It will also permit the prediction of which molecules of interest to the pharmaceutical industry will benefit from crystallization in space conditions (Binot et al., 1998).

In Figure 7, the image is from a research on the ISS. It has been said that in microgravity, crystals grow more slowly, but the molecules have time to more perfectly align on the surface of the crystal which returns much better research data (Julie, 2015).

The other benefits of microgravity research and application in pharmacy are: it allows for longer shelf life of drugs, gives better delivery routes of drugs and allows for better packaging of drugs.

Cells grown in microgravity replicate and grow into complex structures, unlike the way cells grow on Earth (NASA, 2008). Pure, precisely ordered protein crystals of sufficient size and uniformity for X-ray analysis are in demand by the pharmaceutical industry as tools for research. Structural information gained from protein crystals can provide a better understanding of the role of a given protein in the body's immune system. Protein crystal research ultimately aid in the development of more effective drugs and life-saving treatments for many diseases. Microgravity environment allows for the production of high-quality crystals. Protein crystals produced in space are larger and more precisely ordered than those produced on Earth. These improvements are important to scientists who analyze a crystal's 3-dimensional structure-the key to understanding a protein's activity and possibly develop new and more effective drugs (NASA, 2008).

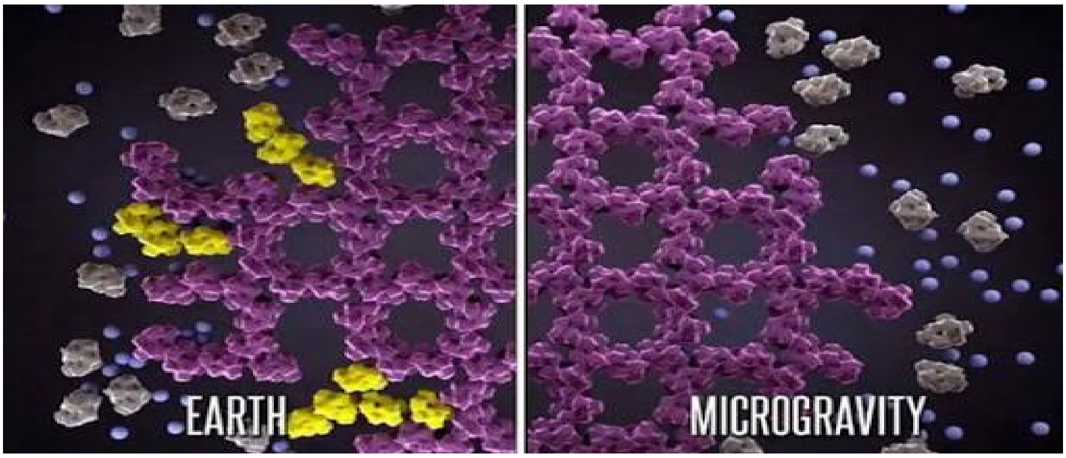

Figure 7: In microgravity, crystals grow more slowly, but the molecules have time to more perfectly align on the surface of the crystal. Image Source – Credits: Brian Dunbar, National Aeronautics and Space Administration (NASA), (2016).

5.5 Benefits of Microgravity Research in Medicine

Millions of people suffer organ or tissue loss from diseases and accidents every year. Yet transplantation of tissues and organs is severely limited by the availability of donors. Growing tissue samples outside the body is one of the major goals of current medical research, and the microgravity environment has great potential for advancing this research. Experiments in bioreactors are performed to study how cells multiply and interact to form skin, bone and organs, and these cells and tissue culturing techniques also aids the study of cancer cells and tumour formation (Kevin et al., 2018). Knowledge gained in microgravity on the regulation of cell growth and differentiation will also help improve the cultivation of sensitive and highly differentiated cell strains like those needed to obtain artificial organs. Studies of cells' ability to migrate in reduced gravity may produce new insights into the factors that allow cancer to spread. When combined with biomedical research on Earth, these investigations could contribute to the development of new ways to prevent and treat related diseases (ESA, 1998).

Simulating microgravity conditions on Earth could increase the preservation time of blood cells both for therapeutic and research applications. To achieve this goal, one must first understand how microgravity acts on the cell metabolism and then create these conditions in blood banks. The use of stored blood cells is of importance in the treatment of bleeding or the pathological deficiency of certain cell types. Platelets and red blood cells must be stored ready to use in blood banks. Improving the preservation conditions would preserve the functional state of the cells and therefore guarantee the efficiency of the treatment while at the same time reducing the treatment costs (ESA, 1998).

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5.4 Benefit of Microgravity to Medical Instrumentation

Monitoring the health and body function of astronauts and related investigations have led to a variety of new insights into the influence of space environment on human beings. Dedicated instruments were developed for medical diagnostics and validated in space, and are now used on Earth. An example is the fluid shift in the human body caused by the absence of hydrostatic pressure observed under microgravity conditions. A dedicated instrument using ultrasound has been developed to measure fluid accumulation in human tissues resulting from such fluid shift. Analogous forms of edema occur preferentially in the facial tissue for kidney disease for example, whereas cardiac patients show edema in the lower part of the body. In this way swellings in the forehead or the tibia can serve as diagnostic or prognostic hints and be controlled by the new ultrasound instrument (Christian, 2016).

For the measurement of inner eye pressure in space (Figure 8), a device which the user can operate without help, has been developed that determines the increase due to microgravity. This 'self-tonometer' can also be used to control the increase of the intra-ocular pressure on Earth. The instrument registers the pressure by total reflection of an infrared beam and is now in the market for regular self-control and diagnostic of patients with risk of glaucoma, one of the most frequent reasons for early blindness. The development of a non-invasive detection instrument to observe eye movements in all three dimensions by video-oculography is another example. The reaction of the eye to light stimulation can be registered continuously and has been used to investigate the coordination of information on orientation obtained by the eye and by the gravity-sensing organ in the inner ear. This method has been successfully tested on space missions, and can be used in the detection of disturbances in the vestibular, neurological or oculomotor domains. This diagnostic instrument is now commercially available for terrestrial use (Christian, 2016; Binot et al., 1998).

Figure 8: Oculography being used to Measure the Pressure of the Eye on the ISS.
Image Source – Credit: Christian (2016).

6. Conclusion

Microgravity researches have the ability to widen our understanding of various challenges that have been faced in life sciences which can in turn generate revenue for nations. Some emerging and aspiring space-faring nations have developed assessment schemes to measure the value of their investments in space and have generally identified positive returns by considering the broader economic implications of space activities. It is generally easier to make the case for space program spending that generates and delivers sustainable value. From this review, haven known the socio-economic benefits of microgravity research, it will be good to intensify effort into it especially in life sciences because of its ability to give novel therapeutics.

The ISS, the drop tower and the 2D clinostat are some of the available platforms for microgravity research. The 2D clinostat is a facility that is very much available for experimental purposes at the Microgravity Simulation Laboratory, Engineering and Space Systems (ESS) Department, National Space Research and Development Agency (NASRDA), Abuja, Nigeria. This equipment is one of the scarce equipment for microgravity research around the globe and especially in Africa.

The concept for a controlled environment for planting in space where there is reduced gravity could be made as spin-offs of space technologies which could lead to other surprising and useful applications on Earth.

Research under microgravity using all the various means described are paramount to pursue and to have a sustained economy, as the space sector is one of the fastest growing sectors in the world. To impede or accelerate progress towards achieving this potential is funding, not just funding but consistent funding, especially to develop robust university programs; as the decisions made on the approach to funding the exploration, exploitation and development of the resources required for microgravity research will determine the speed of progress. Aside funding, awareness of the benefits of microgravity research, especially in life sciences should be created.

References

Andrew, MT. 2003. The Commercial Space Age Conquering Space Through Commerce. Author House, N.Y., pp. 374.

Binot, R., Kufner, E., Minster, O., Routier, D., Sprenger, HJ. and Walter, HU. 1998. Microgravity: A tool for industrial research. European Space Agency (ESA) Publication Division, ISBN: 92-9092-605-8.

Brian, D. 2016. A lab aloft (International Space Station Research), National Aeronautics and Space Administration. https://blogs.nasa.gov/ISS_Science_Blog/author?bdunbar/ accessed on 9 October, 2017.

Brown, RB., Klaus, D. and Todd, P. 2002. Effects of space flight, clinorotation, and centrifugation on the substrate utilization efficiency of E. coli. Microgravity Science and Technology, 13:24–29.

Canadian Space Agency. 2006. What Happens to Bones in Space. http://www.asc-csa.gc.ca/eng/sciences/osm/bones.asp accessed on 19 July, 2019.

Christian, O. 2016. Prospective Observational Study of Ocular Health in ISS Crews (Ocular Health) https://occupymars.wordpress.com/2017/03/ accessed on 9 October, 2017.

Clement, G. and Slenzka, K. 2006. Fundamentals of space biology research on cells, animals and plants in space. New York: Springer Inc.

ESA. 1998. The International Space Station. Microgravity a tool for industrial research. Applied Research on the International Space Station. BR-136.

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Fang, A., Pierson, DL., Mishra, SK. and Demain, AL. 2000. Relief from glucose interference in microcin B17 biosynthesis by growth in a rotating wall bioreactor. Letters in Applied Microbiology, 31:39–41.

Gao, Q., Fang, A., Pierson, DL., Mishra, SK. and Demain, AL. 2001. Shear stress enhances microcin B17 production in a rotating wall bioreactor, but ethanol stress does not. Applied Microbiology Biotechnology, 56:384–387.

Guadarrama, S., Pulcini, EL., Broadaway, SC. and Pyle, BH. 2005. Pseudomonas aeruginosa growth and production of exotoxin A in static and modeled microgravity environments. Gravitational and Space Biology, 18:85–86.

Horneck, G., Klaus, DM., and Mancinelli, RL. 2010. Microbiology Molecular Biol Reviews, 74(1): 121–156.

Jay, W. 2015. https://www.artstation.com/artwork/space-farming accessed on 9 October, 2017.

Jeanne, MD. and John, MO. 2015. The economics of microgravity research. Article number: 15001 (2015) doi:10.1038/npjmgrav.

Jeff, D. 2016. Strides in space farming may boost plan to build human colony on Mars. https://www.cnbc.com/2016/09/29/strides-in-space-farming-may-boost-plan-to-build-human-colony-on-mars.html accessed on 9 October, 2017.

Jessica, N. 2012. Microgravity research coming of age on the International Space Station Program Science Office, NASA's Johnson Space Center. https://www.nasa.gov/mission_pages/station/research/news/microgravity_research.html accessed 9 October, 2017.

Jessika, T. 2019. How space farming works. https://science.howstuffworks.com/space-farming.html accessed 19 July, 2019.

Julie, R. 2015. A Lab Aloft. Four surprising things we learned from research aboard the ISS in 2015. https://blogs.nasa.gov/ISS_Science_Blog/tag/1c/ accessed 19 July, 2019.

Kazuto, S. 2015. The world economic forums global agenda council on space security. Bringing space down to Earth. The global agenda councils. REF 160215.

Kevin, D., Nicholas, ET., Dimakatso, AS., Hendrina, S.,Arielle, R., Collet, D., Michael, P. and Keolebogile, SCM. 2018. Advances in regenerative medicine and tissue engineering: Innovation and transformation of medicine. Stem Cells International. Article ID 2495848, 24. https://doi.org/10.1155/2018/2495848

Lam, KS., Gustavson, DR., Pirnik, DL., Pack, E., Bulanhagui, C., Mamber, SW., Forenza, S., Stodieck, LS. and Klaus, DM. 2002. The effect of spaceflight on the production of actinomycin D by Streptomyces plicatus. Journal of Industrial Microbiology and Biotechnology, 29:299–302.

Lam, KS., Mamber, SW., Pack, EJ., Forenza, S., Fernandes, PB. and Klaus, DM. 1998. The effects of space flight on the production of monorden by Humicola fuscoatra WC5157 in solid-state fermentation. Applied Microbiology and Biotechnology, 49:579–583.

Leys, N., Hendrickx, L., De Bover, P., Baatout, S. and Mergeay, M. 2004. Space flight effects on bacterial physiology. Journal of Biological Regulators and Homeostatic Agents, 18:193–199.

Mark, G. 2017. Benefits for Humanity: Farming from Space. https://www.nasa.gov/content/benefits-for-humanity-farming-from-space accessed on 9 October, 2017.

Mike, D. 2017. Space farming yields a crop of benefits for Earth. Goddard Spaceflight Center. https://www.nasa.gov/feature/space-farming-yields-a-crop-of-benefits-for-earth accessed on 9 October, 2017.

NASA. 1997. Microgravity: Earth and space an educator's guide with activities in Technology, Science, and Mathematics Education. https://www.nasa.gov/audience/foreducatos/topnav/materials/listbytype/Microgravity_Teachers_Guide.html accessed 9 October, 2017

NASA. 2003. Science that can't be done on Earth: Science Mission Directorate https://science.nasa.gov/science-news/science-at-nasa/2003/16jan_sts107

NASA. 2008. Cellular biotech operations support. Microgravity research program fact sheet (01/99) Number: FS-1998-08-006-MSFC.

NASA. 2012. What is microgravity? https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-microgravity-58.html

NASA. 2013. 15 Years of space station facilities advance microgravity research capabilities. https://www.nasa.gov/mission_pages/station/research/news/15_year_facilities accessed on 19 July, 2019.

NASA. 2017. FY 2018 budget estimates. http://www.planetary.org/blogs/jason-davis/2017/20170523-nasa-full-2018-budget-request.html accessed 9 October, 2017.

National Research Council. 2000. Committee on microgravity research. Microgravity research in support of technologies for the human exploration and development of space and planetary bodies. Washington, DC. The National academies press. https://doi.org/10.17226/9452

Nickerson, CA., Ott, CM., Wilson, JW., Ramamurthy, R. and Pierson DL. 2004. Microbial responses to microgravity and other low-shear environments. Microbiology and Molecular Biology Reviews. 68: 345–361.

Oluwafemi, F. 2017. Microgravity research and applications: Roles in economic prosperity and poverty reduction. Proceedings of United Nations/United Arab Emirates, High level forum "Space as a driver for socio-economic sustainable development", Dubai, United Arab Emirates, 6-9 November, 2017.

Oluwafemi, FA., De La Torre, A., Afolayan, EM., Olalekan-Ajayi, BM., Dhital, B., Mora-Almanza, JG., Potrivitu, G., Creech, J., and Rivolta A. 2018a. Space food and nutrition in a long-term manned mission. Springer: Advances in Astronautics Science and Technology https://doi.org/10.1007/s42423-018-0016-2.

Oluwafemi, FA., Oke, AB., and Afolayan, EM. 2018b. Investigation of watermelon seeds growth under simulated microgravity and its advantages to agriculture sector. Monograph of atmospheric research 2018, Centre for Atmospheric Research (CAR), Anyigba, Nigeria, pp. 109-111. ISBN: 978-978-972-859-6.

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Oluwafemi, F. 2018a. Microgravity research applications in life sciences using clinostat. Lap Lambert Academic Publishing. ISBN-13: 978-613-9-90145-6. ISBN-10: 6139901456. EAN: 9786139901456.

Oluwafemi, FA. 2018b. Space Science and Technology in Economic Prosperity. Lap Lambert Academic Publishing. ISBN-13: 978-613-9-97995-0. ISBN-10: 6139979951. EAN: 9786139979950.

Shelley, C. and Brian, D. 2009. NASA- Bones in space. Excerpted from virtual astronaut's bag of bones. https://www.nasa.gov/audience/foreducators/postsecondary/features/F_Bones_in_Space.html accessed 19 July, 2019.

Tara, R. 2019. International Space Station plays role in vaccine development. https://www.nas.gov/mission_pages/station/research/benefits/vaccine_development.html accessed 19 July, 2019.

United Nations. 2013. Teacher's guide to plant experiments in microgravity, Human space technology initiative. United nations programme on space applications, New York.

Valenti, R. 2014. The Most Important Application of Science. Gravitational and Space Biology, 15(9): 919-922. Doi: 10. 15252/embr.201438848

Zerath, E. 1998. Effects of microgravity on bone and calcium homeostasis. Advances in Space Research, 21(8-9): 1049-58

https://www.nasa.gov/mission_pages/station/main/index.html