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Microgravity-simulation of plant growth and its implications to the Sustainable Development Goals

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ABSTRACT: The effectiveness of agricultural enhancement in transforming the world cannot be overemphasized. In line with novel technology in the field of agriculture, the space-industry plays a very significant role in agricultural research and development. Among others, the microgravity-environment is increasingly being seen as having impact on plant development and yield. Hence, the reason why plants are grown and monitored under microgravity-environment to verify their effectiveness both on Earth and beyond. Discussed is an experimental example of plant growth using Clinostat which was done at the Microgravity-Simulation Laboratory, Engineering and Space Systems Department, National Space Research and Development Agency, Abuja, Nigeria. The Clinostat is an equipment for simulation of microgravity effect in an Earth-laboratory. Growing plants under microgravity is to enable fundamental research on gravity perception and transduction during growth and development of plants. The United Nations in 2015 did set a couple of global goals with the sole objective of positively transforming the world. These goals are referred to as the Sustainable Development Goals (SDG). This study explores the contribution of microgravity-simulation to the attainment of some of the SDGs. The research done is mostly in-line with the Zero-Hunger SDG. This work evaluates the effect of microgravity-simulation on okra development and yield. This research will also spur more research in the field of microgravity-simulation. The average growth rate of okra seeds under the Earth's gravity was 3.07mm/h while seeds under microgravity-simulations was 3.50mm/h which means there was an increased growth rate of okra under simulated microgravity by 14.01%.

Keywords: Microgravity-simulations, Clinostat, Plant, Agriculture, SDGs, Okra

Introduction

Gravity is the force that attracts two bodies toward each other while microgravity is when the pull of gravity is not very strong. The term “microgravity” is frequently used as a synonym of “weightlessness” and “zero-gravity”. Weightlessness indicates that the gravity forces are not actually zero but just very small. Weightlessness has been described as “no mechanical support of mass”, and also as a “result from a net sum of all forces present equaling zero, not from absence of gravity” (Briegleb, 1992). Weightlessness happens only in the space environment under real situation. There are now the development of microgravity simulations using several alternative ground-based equipment for the elimination of gravity (Oluwafemi *et al*., 2018).

Plants are absolutely important for the survival of human beings and other living organisms. Plant development is modulated by environmental factors. Among them, gravity is the unique parameter that has remained constant on Earth throughout the entire history of life. All living Organisms are well adapted to this 1g level, which is used by plants to define their developmental pattern and to optimize the capture of light, water, and mineral salts. Consequently, the modification of this parameter would lead to significant physiological changes and would eventually trigger adaptive mechanisms. Gravity is considered as one of the most important factors differentiating the Earth environment from the outer space or exoplanets. Studying plants in microgravity condition, allows for the understanding of how plants respond to gravity. Research under the condition of microgravity here on Earth has contributed greatly to the knowledge of the impact of gravity on plant orientation and growth. Since plants are very important and play a vital role in human’s life and also in the space exploration, therefore, the study of plants root is very important as they respond to gravity positively.

Plant root-anatomy is important for gravi-responses. Therefore, roots study provides with information on fundamental biological processes (Hoson *et al*., 1992) as, in the roots are the dividing tissue, also known as meristematic tissue. Apical meristem is present at the growing tips of stems and roots and increases the length of the stem and the root. More so, the whole of a plant grows from a seed through the seed’s root and shoot. Basic biochemical information such as antioxidant enzyme assay from the root of a seed may serve as the answer to the information needed on a particular plant. As plants are important for spaceflight and plants responding to gravity is important with respect not only to plant breeding and agriculture on Earth but also to growing plants in space (space farming) and ensuring a supply of oxygen and food during long-term space missions (Ferl, 2002)

Fig 1 shows an example from the Mars One Habitat Housing Concept (Mars One is a group of individuals who research towards future Mars mission) whereby in the habitat, the plants grown produces oxygen in the habitat while plants uses the carbon dioxide from astronaut’s breathing for respiration. The plants grown also serves as food for astronauts.

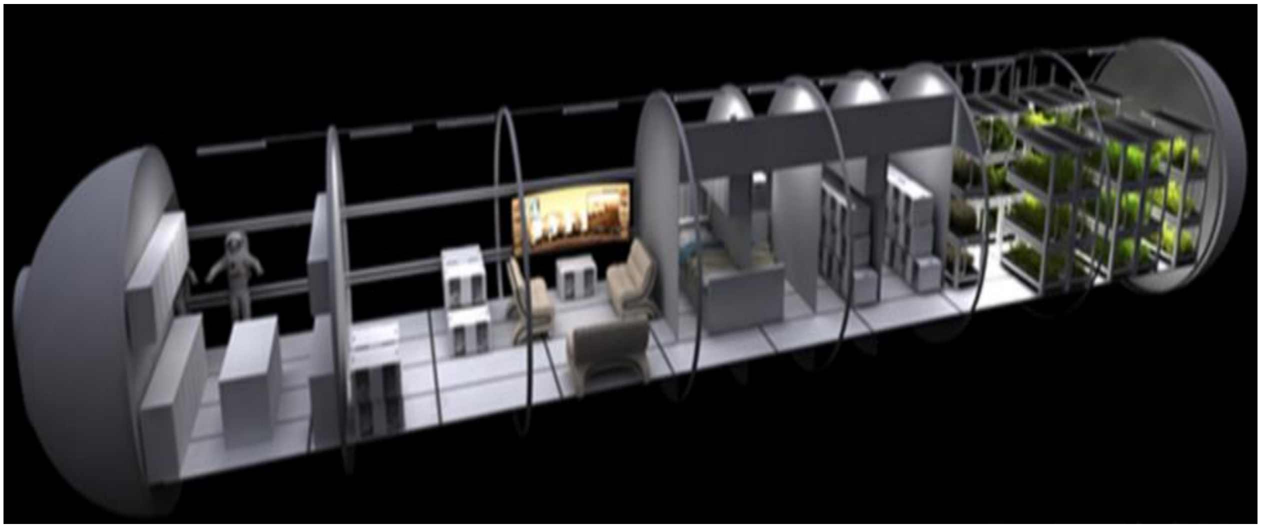

Fig 1: Internal view of the Mars One Habitat Housing Concept. Image Source: Mars One, 2015

The effectiveness of agricultural enhancement in transforming the world cannot be overemphasized. The microgravity-environment (or simulated microgravity platforms) of space makes it an excellent biological laboratory. Cells, microbes, plants, macromolecules and samples from material science 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 or provide new insights into certain processes and phenomena (Oluwafemi, 2017). In line with novel technology in the field of agriculture, the space-industry plays a very significant role in agricultural research and development. Among others, the microgravity-environment is increasingly being seen as having impact on plant development and yield.

Discussed is an experimental example of plant growth using Clinostat which was done at the Microgravity-Simulation Laboratory, Engineering and Space Systems (ESS) Department, National Space Research and Development Agency (NASRDA), Abuja, Nigeria. In the laboratory, the Clinostat is an equipment for simulation of microgravity effect. Microgravity-simulation usually results in the need to consider additional environmental parameters which appear as secondary effects that interferes with gravity alteration in the changes observed in the biological processes under study. Plants were chosen as test systems since they are easily available and their experiment demands are easy to meet.

Various kinds of Clinostats have been developed, differing in the number of rotational axes and the modes of operation with respect to the speed and direction of the rotation. A two-dimensional (2-D), or uniaxial (one-axis), Clinostat has a single rotational axis, which runs perpendicular to the direction of the gravity vector ((Briegleb, 1992; Dedolph, and Dipert, 1971; Klaus, 2001). A one-axis Clinostat was used in this project. It can provide a rotational speed in a range of 0 to 90 revolutions per minute (rpm). The specifications of the one-axis Clinostat are shown in Table 1 below, while Fig 1 shows the picture. The 2D Clinostat used in this project was made by Advanced Engineering Services., Co. Ltd. It’s the model UN-KTM2 REV. NC. 2012.11.

This 2-D Clinostat was won after a series of examinations by Oluwafemi, Funmilola Adebisi (the first author of this paper) for NASRDA from United Nations Office for Outer Space Affairs (UNOOSA) in the United Nations Human Space Technology Initiative (UN-HSTI) “Zero-Gravity Instrument Project” (ZGIP), 3rd Cycle, in 2015. This made for collaboration of NASRDA with UNOOSA. This collaboration with the United Nations is for both research and educational purposes (Oluwafemi, 2016; UNOOSA, 2015; UNOOSA 2016).

The Human Space Technology Initiative was launched in 2010 within the framework of the United Nations Programme on Space Applications. The role of the initiative is to provide a platform to exchange information, foster collaboration between spacefaring and non-spacefaring countries and encourage emerging and developing countries to take part in space education and research and to benefit from space applications. Those activities are built on three pillars (Oluwafemi, 2016; UNOOSA, 2015; UNOOSA 2016):

(a) promoting international cooperation in human spaceflight and activities related to space exploration.
(b) creating awareness among countries of the benefits of utilizing human space technology and its applications; and
(c) building capacity in microgravity science education and research

Table 1. Specifications of the One-Axis Clinostat

Rotational speed	0-90 rpm 0-20 rpm: 0.5 rpm increments 20-90 rpm: 5 rpm increments
Rotational axis angle	0° (parallel to the ground) to 90° (perpendicular to the ground)
Rotation direction	Clockwise or counterclockwise
Experiment conditions	Maximum weight of samples: 500 g
	Maximum diameter of a sample container: 10 cm

Fig 2: The uniaxial (2-D) Clinostat (in horizontal position) and its control box. Image Source – Credit: Microgravity-Simulation Laboratory, Engineering and Space Systems Department (ESS), National Space Research and Development Agency (NASRDA), Abuja, Nigeria

The United Nations General Assembly in 2015 did set a couple of global goals with the sole objective of positively transforming the world. These goals are referred to as the Sustainable Development Goals (SDGs). Sustainable development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs. Sustainable development in an economy includes economic growth, environmental protection and social equality (Oluwafemi, 2018). There are 169 targets for the 17 goals. Each target has between 1 and 3 indicators used to measure progress toward reaching the targets. In total, there are 232 approved indicators that will measure compliance. The goals are (see Fig 3) (United Nations, 2015a; United Nations, 2015b):

Goal 1: Zero poverty
Goal 2: Zero Hunger
Goal 3: Good health and well-being
Goal 4: Quality Education
Goal 5: Gender Equality
Goal 6: Clean water and Sanitation
Goal 7: Affordable and clean energy
Goal 8: Decent work and Economic Growth
Goal 9: Industry innovation and infrastructure
Goal 10: Reduced inequality
Goal 11: Sustainable cities and communities
Goal 12: Responsible Consumption and production
Goal 13: Climate action
Goal 14: Life below water
Goal 15: Life on land
Goal 16: Peace and justice strong institutions
Goal 17: Partnership to achieve the Goal

Fig 3: The Sustainable Development Goals (SDGs). Image Source: United Nations, 2015a

This project explores the contribution of microgravity-simulation to the attainment of some of the SDGs. These SDGs are Zero-Poverty; Zero-Hunger; Good Health and Well-Being; and Quality Education. The research done which is mostly in-line with the Zero-Hunger SDG evaluates the effect of microgravity-simulation on plant development and yield. This research will also spur more research in the field of microgravity-simulations.

Discussions are made on SDG 1: Zero-Poverty; SDG 2: Zero-Hunger; SDG 3: Good Health and Well Being; and SDG4: Quality Education, in relation to plant microgravity-simulations research.

Okra (*Abelmoschus esculentus*), is an important fruit used for soup in Africa and it was selected in this research because of its nutritional benefits. It has a high dietary fiber content which is an important nutrient that helps to prevent weight gain and heart disease, hence it is of great importance to study the influence of microgravity on growth and development in okra. The following properties was also a determinant for the choice of okra in this research: its small size; easy to handle; and its fast growth. These are criteria for use on the Clinostat. Microgravity, as a different environment, has been shown to affect plant growth and development (Sievers *et al*., 1996; Sack, 1997). Several reports have described the effects of clinorotation on physiology of plants and cell biology (Hilaire *et al*., 1995a), calcium distribution ((Hilaire *et al*., 1995b), protein expression (Piastuch and Brown, 1995), carbohydrate metabolism (Brown and Piastuch, 1994; Obenland and Brown, 1994) and the cell cycle (Legue, 1992). Rotation on a Clinostat is called clinorotation. The difference in the germination and early growth of okra under Earth's gravity and simulated microgravity was analysed in this project by determining the growth rates using ImageJ software to measure roots lengths.

Microgravity-Simulations of Plant

In order to discriminate the role of microgravity from that of other factors in regulation of growth and development, it is necessary to observe the changes in each growth process under micro and hyper -gravity environment. The history of research on gravitational effects on plant seedlings is relatively long. There are different techniques to create the micro- and hyper-gravity to examine the plant growth process under various gravity conditions. However, there are real and simulated practicable way to achieve microgravity.

Microgravity simulators are variety of experiment platforms that have been developed to achieve simulated microgravity conditions. They are used to demonstrate gravity sensitivity of ecosystem, to develop and test flight hardware, and to counter measure and to support statically the results obtained in real microgravity. As gravity strongly influences plant growth and development on Earth, in other words it is needed to observe the changes in each growth process under a weightless environment (Hoson *et al*., 1992).

Plants are essential for the coming enterprises of manned space exploration as part of life support systems required to feed humans during long spaceflight and for survival outside the planets. For this purpose, plants need to be adapted to grow in near zero-gravity (space) and in fractional gravity. Microgravity conditions can be produced on Earth using Clinostats (Hoson *et al*., 1997). Alternatively, on Earth experiments with Clinostat have been done and used for simulating microgravity condition in plant science.

The Clinostat is a simple equipment used to create the artificial gravity by controlling the centrifugal force for different values of angular velocity. Using experimental platforms such as 2-D Clinostats. The 2-D Clinostat has been defined as a tool to obtain a "vector-averaged gravity" (Sarkar *et al*., 2000) or to provide the nullification of the gravity stimulus" (Dedolph *et al*., 1967). In simulation experiments, the magnitude of the Earth gravity-vector cannot be changed only its influence or effect can be changed (Briegleb, 1992).

When using a Clinostat, the speed of rotation, the diameter and time sensitivity of the sample and the horizontal placement of the Clinostat are essential parameters which determine the effectiveness of microgravity-simulation (United Nations, 2013).

The first factor to be considered is the speed of rotation of the clinostat. The faster the system rotates, the more the radii of the circles decrease. If the rotational speed is too high, however, particles will disperse due to the centrifugal force. At an ideal rotational speed, particle movement due to sedimentation and centrifugal force is kept within the limits of Brownian motion. Transferring this condition to the level of gravity-perceiving cells (statocytes), it can be predicted that the sedimentation of statoliths can be suppressed under the ideal simulation conditions in a clinostat. In a slow-rotating clinostat experiment (1-2rpm), due to the relatively long response time of plants, the gravitropic response is suppressed under these conditions. The second factor to be considered when using a clinostat is centrifugal force, which is in proportion to the distance between the sample and the axis of rotation and the rotational speed (rpm) squared. If the rotational speed is too high, then the centrifugal force acting on statoliths will move them towards the cell wall. The third factor to be considered is the horizontal placement of the rotational axis of the clinostat. The rotational axis must be placed horizontally as accurately as possible (United Nations, 2013).

Microgravity-Simulations of Plants with Related Sustainable Development Goals (SDGs)

SDG 1: Zero-Poverty

This goal is for eradicating poverty in all its forms by 2030. This remains one of the greatest challenges facing humanity. The SDG response to this is to create opportunities for good and decent jobs and secure livelihoods. Ending extreme poverty globally by 2030's target may not be adequate for human subsistence and basic needs; however, it is for this reason that changes relative to higher poverty lines are also commonly tracked. Poverty is more than the lack of income or resources: People live in poverty if they lack basic services such as healthcare, security, and education (United Nations, 2015a).

Microgravity-simulations research has created opportunities for people to be researchers, scientists etc. Plant simulation microgravity research can help reduce poverty through the various benefits in agriculture. It also gives more insight on how to produce better products that will in turn boost the economy (NASA, 1997). This makes it to increase economic prosperity and to reduce poverty (Oluwafemi, 2017, Binot *et al.*, 1998).

More than 818 patents have been granted from 1981 to 2012 as related to the subject of microgravity, 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.

SDG 2: Zero-Hunger

This is the agricultural SDG. The effectiveness of agricultural enhancement in transforming the world cannot be overemphasized. This SDG is to end hunger, achieve food security and improve nutrition, and promote sustainable agriculture. Goal 2 states that by 2030 hunger and all forms of malnutrition should have ended. This would be accomplished by doubling agricultural productivity and incomes of small-scale food producers, by ensuring sustainable food production systems (United Nations, 2015a).

In line with novel technology in the field of agriculture, the space-industry plays a very significant role in agricultural research and development. Hence, the reason why plants are grown and monitored under microgravity-environment is to verify their effectiveness both on Earth and beyond. Growing plants under microgravity (or simulated microgravity) environment is to enable fundamental research on gravity perception and transduction during growth and development of plants.

SDG 3: Good Health and Well Being

This is to ensure healthy lives and to promote well-being for all at all ages. Significant strides have been made in increasing life expectancy and reducing some of the common killers. To achieve this, there is a need to fight communicable diseases like tuberculosis, malaria and neglected tropical diseases, and to achieve universal health coverage. Goal 3 aims to achieve universal health coverage, including access to essential medicines and vaccines (United Nations, 2015a).

Microgravity research on plant used in treatment of these diseases is thereby advisable to be done as microgravity-environment is an excellent biological laboratory for example that allows for the change in protein structure (which is not possible under normal Earth gravity) which then allows for a new drug to be produced (Oluwafemi, 2017; Binot *et al.*, 1998).

SDG 4: Quality Education

This goal is to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. Major progress has been made in access to education, specifically at the primary school level and access does not always mean quality of education or completion of primary school. This goal is to ensure access to quality education (United Nations, 2015a) until is a great gain for such a person.

Microgravity-simulations experiment enhance space science and agricultural education for example at the Microgravity-Simulations Laboratory, ESS Department, NASRDA, Abuja, Nigeria. Obtaining a quality education is the foundation to improving people's lives and sustainable development. In Africa, astronomy and space science researches are novel, therefore, microgravity-simulation experiment using Clinostat at NASRDA is used to popularize in educating and researching in space science among a wide age range of 7 to 45 years of interns, students on excursion and staff (for capacity building). The Clinostat eliminates the effect of gravity, which would have only been possible in the real space region. Since no Nigerian or any African has been able to go for experiments in any of the Space Laboratories because such experiments are rare and expensive. The Clinostat therefore makes it possible for us to perform microgravity experiments in an Earth laboratory. This make students to learn or study microgravity science. These type of inquiry-based experiments or projects allow students to be involved in human space exploration with the goal of simulating their studies in Science, Technology, Engineering and Mathematics (STEM) on space exploration (Oluwafemi, 2016).

Experimentation: Plant Growth Under Microgravity-Simulation Using Clinostat

This was done at the Microgravity-Simulation Laboratory at ESS Department, NASRDA, Abuja, Nigeria. In this research, the Clinostat was used for the germination of okra seeds to investigate the effect of gravity.

Methodology

Okra seeds were bought and authenticated to be the actual seeds sought after. The Clinostat that was used for this research is a one-axis Clinostat (desk-top type) (Fig 2). It operates with respect to speed and direction of the rotation. The following properties was also a determinant for the choice of okra: its small size; easy to handle; and its fast growth with germination period of 2 days. These properties make the seeds useable on the Clinostat as the 2-D Clinostat (Desk-top type) used does not accommodate more than 500g of sample.

The substrate of the seeds called plant agar-agar was prepared into 2 petri-dishes following the standard preparation method in the Teacher's Guide to Plant Experiments by UNOOSA of the Programme on Space Applications (United Nations, 2013), then the okra seeds were planted in the substrate and it was cultivated inside a wet chamber in vertical positions. After 2 days, germination of the seeds with short roots was observed. The 2 petri-dishes were then taken and labeled differently "1g-control" and "Clinorotated". The 1g-control sample was remained in the vertical position and the Clinorotated sample was then placed at the centre of the Clinostat using double-sided tape. The photos of the 2 petri-dishes were taken every 30 minutes with very short stopping time of the clinorotated in order to avoid the effect of gravity. These observations were done for 6hr under the following conditions. Humidity between 60% to 100%, temperature of 23□C and light of 50lx. In addition to these, the Clinorotated sample had the following conditions, rotation speed of 80rpm, rotation position of Clinostat was horizontal, and the direction of rotation was clockwise. At the end of observation, the analysis of growth rate was carried out (United Nations, 2013). The pictures of the two samples are in Figs 4 and 5. In this research, the light-conditions, temperature, humidity, rotation-direction and rotational-axis angle (horizontal) (see Fig. 2) were kept constant while the time of observation was for 6hr.

Fig 4: Picture of the mounted Clinorotated sample

Fig 5: Picture of the 1g-control sample

Data Analysis: Growth Rate of the Root

The pictures of the 1g-control and the Clinorotated roots were used for this analysis. The difference between the two cases was analyzed by measuring the length of the roots, which thereby allowed their growth rate to be determined. For the analysis of the length of the roots, the length of the roots was measured with a ruler or drawing a line which is exactly 10mm long on each petri-dish and the growth rate analysis was done using the ImageJ software. This was done by using the length measurement tool and measuring a fixed length in the photo. Fig 6 shows lengths of the 1g-control sample roots and Clinorotated sample roots versus the time after germination. The graph was plotted using the grand average from Table 3. The average growth rates (shown in Table 2) were calculated (millimetres/hour) for the 1g-control and the Clinorotated roots.

Results

The average growth rate of the roots for the 1g-control sample was 3.07mm/hr while that of the Clinorotated sample was 3.50mm/hr.

Note that from the Figs 4 and 5, and as indicated in Table 2, a seed of okra did not grow in the Clinorotated sample while one seed in the 1g-control fell off the agar-agar, which wouldn't matter as the average of the other 8 seeds was used for analysis.

Table 3: Grand Averages of the Growth Rate Analysis Using the Root Lengths of the 1g-control and Clinorotated Samples of Okra

Time (hr)	1g-control (mm)	Clinorotated (mm)
0	17.47	17.38
0.5	16.32	17.78
1.0	17.87	18.51
1.5	15.03	16.45
2.0	17.87	17.77
2.5	16.82	23.07
3.0	19.84	23.58
3.5	20.56	24.89
4.0	20.50	22.58
4.5	18.07	20.52
5.0	20.42	23.51
5.5	18.27	22.55
6.0	20.20	24.06
Average	**18.40**	**20.98**

Since the plant was examined for 6 hours, therefore, the growth rate of the 1g-control sample is: 18.40/6 = 3.07mm/hr.

The growth rate of the Clinorotated sample is:

20.97/6 = 3.50mm/hr.

Percent increase in the growth rate of the Clinorotated Sample compared with the 1g-control sample.

3.50mm/hr - 3.07mm/hr = 0.43mm/hr

$$\frac{0.43}{3.07} \times 100$$

$= 0.1400651465 \times 100 = 14.01\%$

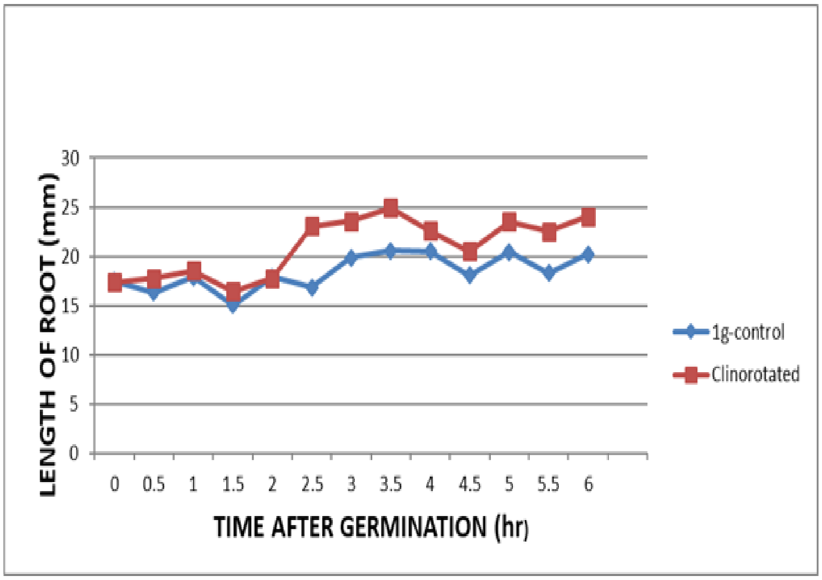

Fig 6: This graph is an experimental result with the length of the 1g-control sample roots and the Clinorotated sample roots versus the time after germination

Discussion

The goal 1 of the SDG (Zero-Poverty) is for eradicating poverty in all its forms by 2030. Space technology applications such as in microgravity stimulate economic growth and improve the quality of life of people; thereby beneficial to mankind. Once there is economic prosperity, then poverty will be reduced (Oluwafemi, 2018). 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. More than 818 patents have been granted from 1981 to 2012 as related to the subject of microgravity, the use of patents as an indicator of value creation signifies economic potential (Jessica, 2012).

Uhran, former NASA director, International Space Station (ISS) Division Human Exploration and Operations Mission Directorate, points out that the use of patents as an indicator of value creation signifies economic potential. In addition to the granted patents, he cites an additional 580 applications 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." 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 (Jessica, 2012).

Other targets of the SDG goal 2 (Zero-Hunger) apart from doubling agricultural productivity and incomes of small-scale food producers, deal with maintaining genetic diversity of seeds, increasing access to land, preventing trade restriction and distortions in world agricultural markets to limit extreme food price volatility, eliminating waste with help from the International Food Waste Coalition, and ending malnutrition and undernutrition. Globally, 1 in 9 people are undernourished, the vast majority of whom live in developing countries (United Nations, 2015a). Microgravity-simulations of plants allows for bio-diversity of seeds. Development of new plant variety adapted to extreme condition and the production of better products is made possible under microgravity-simulations. For example, the gene of a seed that had a better growth rate under microgravity-simulations can be isolated and inserted into the gene of a non-clinorotated seed. This then will make the plant to have a better growth rate when planted on the field.

The use of simulated-microgravity environs for planting also provides some solution to land scarcity and deforestation caused by agricultural purposes. In the Vegetable Production System (veggie) used in the ISS for growing vegetables under microgravity, vegetables have been harvested and eaten by astronauts (Herridge, 2017). Other big microgravity-simulations facilities in the forms of big rooms on the Earth can be made available to grow plants preventing deforestation and serving as a solution to land scarcity for agricultural purposes.

As the goal 3 of the SDG (Good Health and Well Being) aims to achieve universal health coverage, including access to essential medicines and vaccines (United Nations, 2015a). Microgravity or microgravity-simulations research on plants used in treatment of specific diseases is advisable as microgravity-environment is an excellent biological laboratory. For example, microgravity environment or microgravity-simulations environment allows for change in protein structure (which is not possible under normal Earth gravity) which can then allow for a new drug to be produced (Oluwafemi, 2017; Binot *et al.*, 1998).

The UN-HSTI “Zero-Gravity Instrument Project” (ZGIP) with which NASRDA has a collaboration with United Nations for both research and educational purposes (Oluwafemi, 2016, UNOOSA, 2015, UNOOSA 2016) has a great contribution to SDG 4: Quality Education. This singular collaboration has helped to research on ten plants indigenous to Nigeria by growing them under simulated microgravity and comparing their growth to that of the control under normal Earth gravity. The educational activities on microgravity has also being highly impactful and productive at NASRDA as people of age range of 7 to 45 are being taught on the topics: microgravity, microgravity-environment, microgravity science and microgravity experiment practical using the Clinostat. The various applications of microgravity to man is also usually explained to them.

Plant growth in the space environment is useful to the astronauts since they can breathe the oxygen the plants are giving out while the plants also take-in the carbonIVoxide the astronauts breath out. During long duration spaceflight and in the Space Laboratories such as the ISS, this mutual relationship is quite important. This is because the lives of the astronauts are paramount, and the major focus is to keep them alive, happy and healthy (Oluwafemi *et al.*, 2018). Plant growth is also indispensable for all life on Earth because photosynthesis is needed for food and oxygen production.

Identifying, designing and predicting technology requirements for Environmental Control and Life Support System (ECLSS) for colonizing celestial bodies such as Moon and Mars is the first task need to be performed to keep astronauts alive. The conceptual design for the ECLSS assessment can address food, hygiene, exercise, medical, lighting, radiation protection etc. After crew’s arrival on the celestial body, the ECLSS continues to deliver N_2, Ar, O_2 , and H_2O, and removes CO_2 and trace contaminants to meet crew’s metabolic needs to maintain a safe breathable atmosphere. The Life Support System includes food and water production. Therefore, how plants grow in the Moon or Mars for the survival of astronauts for long space missions is quite important.

It is evident that the Moon planting of the China’s Chang’e4 biosphere experiment is a laudable action. As seeds of cotton (*Gossypium*), oilseed rape, potato and Arabidopsis were carried to Moon along with fruit fly eggs and some yeast as an attempt to create a self-sustaining mini biosphere (Barbosa, 2019). This was done in order to solve the problem of limited food and oxygen resources, as Bio-regenerative Life Support Systems (BLSS) are envisioned with closed nutrient and gas loops (Hader *et al*., 2018). Therefore, the research done in this project, when done in real microgravity environment where there is little or no atmosphere, it will be of great importance to survival. This is in-line with Mars one, 2015 habitat design proposal for astronauts in Mars (see Fig 1).

Oluwafemi *et al*., 2018 suggested extrapolating growth rates of seeds from microgravity/microgravity simulation platforms to develop mathematical /theoretical models for plant growth on the various celestial destinations and to know if the seeds will give the crew members the desired quantity of nutrients.

From the experimental example given in this project, the average growth rate of the roots for the 1g-control sample was 3.07mm/hr while that of the Clinorotated sample was 3.50mm/hr which means there was an increased growth rate of okra under microgravity by 14.01%. This is in conformity with the experiment of Emmanuel *et al*, 1996 that there was doubling of the root length of seeds under clinorotation (Clinostat rotation) compared to the stationary control in similar experiment.

From Fig 6, there are two intersection points of the curves for the 1g-control sample and the Clinorotated sample, this means that their roots lengths are the same at the corresponding times after germination.

Since the constituents of these seeds are food nutrients, therefore it means that under microgravity, there was an increase in the food nutrit of okra seeds. It is evident from the result that when okra is taken to a microgravity-environment such as the International Space Station (ISS), the astronauts will be having more nutrients after its germination and probably harvest, than that which they would have gotten on the Earth. This will be in-line with the work of Raghad *et al*, 2016 that investigated that gravistimulation produced on corn using Clinostat showed enhanced amino acid concentration more than the control. Based on their result it was concluded that clinorotation can affect the biochemicals in plants tissue positively.

This experiment also created data set of experimental results in gravity responses that can contribute to the design of future space experiments and to the advancement of microgravity research. This in all adds to the analytical knowledge to compare with subsequent spaceflight experiments.

Further work will be on the effects of protein profile as well as other biochemical changes such as the antioxidant enzyme assays in simulated microgravity grown culture in comparism to the control under normal Earth gravity. Examination of other okra root anatomy and microscopic analyzes of the cells after simulated microgravity impact will also be a further work.

Conclusion

The space sector is now growing fast in the world, and space technologies are currently being used to achieve the SDGs in which microgravity research is part of it. From the various discussions and experimental example given in this paper, it is evident that microgravity-simulations application on plants, stimulates economic growth and improves the quality of life of people which therefore is in-line with the achievement of SDG 1: Zero-Poverty; SDG 2: Zero-Hunger; SDG 3: Good Health and Well Being; and SDG4: Quality Education.

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