



## PLANT PHYSIOLOGY AND GROWTH IN MICROGRAVITY

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### Abstract

This paper will examine the response to the *Arabidopsis thaliana* that was grown under a microgravity environment on the International Space Station (ISS) at both the cellular, molecular and physiological level. We employed mixed-methods experimental design and involved high-resolution imaging, phenotypic attribute measurement of chlorophyll fluorescence, gas exchange, and transcript profiling. Growth modelling indicated that microgravity affected the process in the growth of things significantly, which is a reduced gravitropic root curvature, alterations in the expansion of leaves, and variations in the photosynthetic efficiency. The analysis of the gene expression revealed that the pathways able to respond to the stressful conditions, arrange the cytoskeleton and remodel the cell wall were changed differently. Statistical testing indicated that the changes were noteworthy such that  $p < 0.05$ , thus supporting the fact that microgravity induces a coordinated response in the physiology and genetics domains. The findings depict how plants have the abilities to grow and transform in extraordinary manners in the absence of gravity. They also provide us with good data to design closed-loop bioregenerative life-support systems to explore space. This research teaches us more about the way plants adjust to the conditions of existence in space and precondition further space agriculture programs.

**Keywords:** Microgravity, Plant Physiology, Space Biology, *Arabidopsis Thaliana*, Space Agriculture, Gene Expression

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## INTRODUCTION

One of the fundamental characteristics of space habitats that has a major impact on the growth and development of plants is microgravity. This poses challenges as well as an opportunity in the future in terms of long-time space exploration and working in other planets. The absence of the constant gravitational force experienced on the Earth throws off the basic functions of plants. This influences the way in which they grow, the way in which their cells are configured and the way in which their biomass is distributed in general (Farooq et al., 2024). Understanding the mechanics of these processes is required in order to develop more sustainable bioregenerative life support systems that use plants to produce oxygen, scrub off carbon dioxide, supply nutrients, and maintain astronauts mentally fit during longer space flights (Medina et al., 2021). This leads us to the future of growing plants in situ, which is increasingly becoming significant as we get nearer to having a permanent human population on other planets; as the feasibility through which such a feat could be achieved draws closer, the capability to grow plants in situ becomes all the more important in the sense that there will always be food and resources available (Handy et al., 2021; Hummerick et al., 2021). The environments in space are special, and it is desirable to comprehensively understand the reaction of plants to their molecular, cellular, and whole-organism levels (Totsline et al., 2023) due to, among other things, microgravity, exposure to radiation, and differences in light spectra. All the changes in gene expression, cell growth and differentiation, signalling and physiological processes may occur in space due to alterations in both gravitational fields and as a result of exposure to radiation. The proposed changes may even alter the way the entire plant functions since they may interfere with the organization of tissues and organogenesis (Micco et al., 2023). Plants that

are subjected to spaceflight are transformed transcriptionally and epigenetically (Du et al., 2024). There is much potential that plants in space may alter, resulting in larger crops (Mohanta et al., 2021). In the case of a future mission to human space travel, in which it will not be possible to take materials to earth, plant space biology must take a step forward (Micco et al., 2023). Life in photoautotrophic organisms can construct numerous compounds using only carbon dioxide, water and mineral nutrients (Mortimer & Gilliam, 2021). There is also the need to understand how plants respond to all the various conditions on earth, and the unique conditions in space, which includes the altered gravity, ionizing radiance, limited space (Pascale et al., 2021). Space environment forms new biophysical combinations and new ways to grow crops and change the crops themselves necessitate the best growth and production on Earth crop farm modules that grow crops in space in space farm modules (Curry et al., 2024). Researching the way plants become adjusted to these new environments may result in the introduction of new applications to land-based farming, which will render crops more robust and resourceful. As an example, enhancing plant growth under controlled conditions such as in vertical farms may solve the radiations and temperature control problem in space besides utilizing the resources at the best possible extent. That would benefit the sustainability initiatives of the planet (Kamran et al., 2023). Microgravity influences significant components of plant physiology in a large way. As an example, it prevents gravitropism, the manner in which roots and shoots grow to respond to gravity. The lack of the strong gravitational vector can make the growth of roots less guided, so, it can make it harder to absorb all the water and nutrients into the plant. The growth of the shoots might also be modified, and it

might impact the ability of the plant to absorb light and its general form (Farooq et al., 2024). To adapt to space travel, plants modify the production of their cell walls, redox/microtubule dynamics, and plastid gene transcription (Kruse et al., 2020). It is also possible to alter the reaction of genes responding to stress through spaceflight settings (Angelos et al., 2020). This complicates the optimal plant growth in space, since practices of dripping water on and feeding plants with nutrients as otherwise could be done on Earth might not be possible without gravity-driven fluid dynamics. Consequently, space-based plants growing systems are increasingly incorporating new techniques such as hydroponics and aeroponics, where the transfer of nutrients to the root system happens without the assistance of gravity (Nguyen et al., 2022). The usage of microgravity also varies the motion of water and nutrients through the plant, and affects the transpiration levels and the dispersions of nutrients (Khodadad et al., 2020). It is also quite essential to study the flow of water in the microgravity context as it influences the physiology of higher plants, such as the way they are nourished and discard waste materials (Giordano et al., 2023). In Earth, gravity plays a very important role when it comes to transportation of water using xylem and phloem, however in microgravity pressure gradient and capillary action factors replace this influence. This may trigger unequal water distribution and tension in some parts of the plant tissues. One should know about these alterations in the body to enhance water and nutrient delivery systems in space agriculture. In space also, plants experience greater stress such as they are subjected to increased levels of radiation which can widen DNA breaking it and causing cells to cease to functional well. These features indicate that we must be extremely cautious about the line we take in selecting plant species that would be able to withstand such conditions and devise means of

reducing adverse effects of spaceflight on plant health. Therefore, to design long term life support systems and develop food to support astronauts on long space missions, every possible aspect of the interaction of microgravity on plant biology must be learnt. Bioregenerative life support systems in space could work with plants. It is highly important that the species of the plants which would grow in space are selected. It should be made on such factors as nutritional value, growth rate, resources use, and survival of the plants in the space. A wonderful addition to astronaut diets would be microgreens since they contain many phytonutrients and grow fast. They are able to provide astronauts with valuable vitamins and antioxidants that space foods cans lack (Izzo et al., 2023). Provision of fresh and healthy foods to astronauts on long space missions is quite significant since long-term diets consisting solely of processed meals available on Earth may trigger dangerous nutrient deficiencies (Giordano et al., 2023). To cure this, researchers are trying to create maximum efficient plant-based space food growing systems. They are paying attention to the significance of recycling nutrients/ waste management, closed-loop biospheres, to make the systems more sustainable (Tang et al., 2021). Research shows that there is a possibility to grow plants such as red romaine lettuce on the International Space Station (Khodadad et al., 2020). By consuming more nutrients in form of fresh fruits and vegetables that are produced in space, astronauts will have a chance to consume more nutrients and even feel mentally better (Bunchek et al., 2024). In addition, the variation in the levels of vitamin C in plants demonstrates the significance of establishing AI to assist astronauts in the selection and production of vegetable crops with high levels of vitamin C to prevent the threats of radiation and microgravity (Mortazavi et al., 2024).

## METHODOLOGY

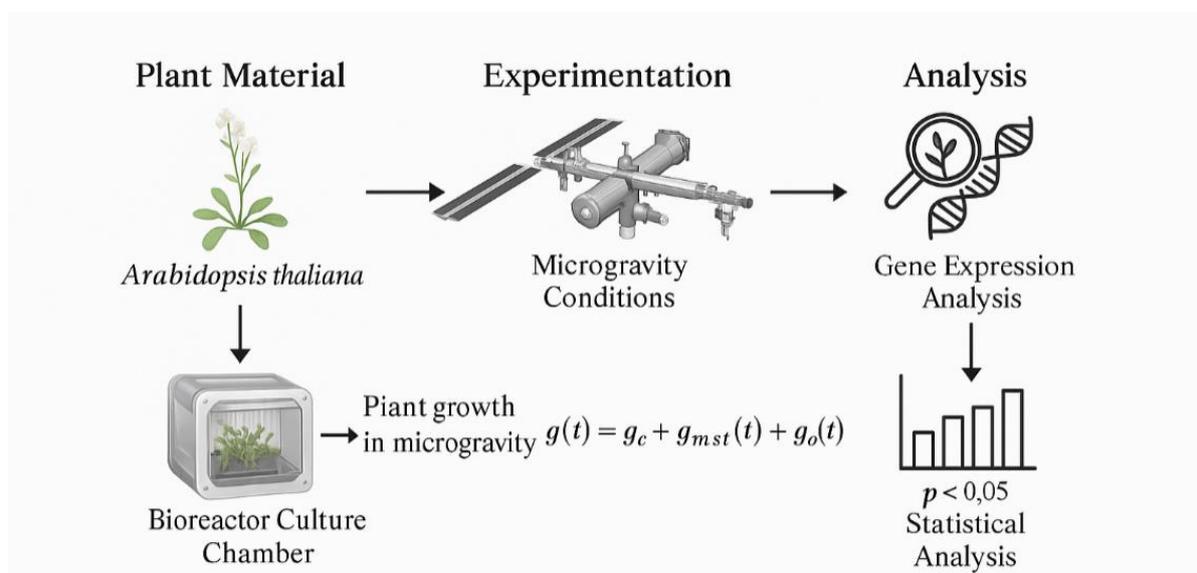
To examine the way that plants grow in microgravity, it involved a mixed-methods experimental design, with both quantitative physiological data and qualitative morphological analysis. The model organism used was *Arabidopsis thaliana* due to its genome being well characterized, it has a short life cycle, and is already utilized as a model in space biology studies. Seeds were sterilized on the surface prior to the germination in a controlled room which provides the cultivation. In moving the seedlings to the International Space Station (ISS), they would be placed in a sealed bioreactor culture chamber equipped with automated nutrient delivery systems and environmental controls so that they could easily be assured of getting the correct environment of water, air, and light. The microgravity experiment conducted to grow things lasted 21 days with 16 hours of light and 8 hours of darkness per day. Our measure was how was microgravity influencing the plant physiology and we modelled the plant growth as:

$$g(t) = g_c + g_{mst}(t) + g_o(t)$$

where  $g_c$  indicates increases at baseline conditions in controlled earth like conditions,  $g_{mst}(t)$  indicates microgravity stress changes over time  $t$ , and  $g_o(t)$  indicates other operational or environmental changes. Photographing was done in high definition where we

measured morphological parameters, e.g. hypocotyl length, root architecture and leaf expansion. We analyzed the data by use of digital image processing. We further employed onboard sensors to measure chlorophyll fluorescence and gas exchange to determine how efficient is the process of photosynthesis and how efficient is the opening of the gas exchange of the stomata. In order to study the molecular structure, the samples of leaf tissues were collected at some of the stages of growth, frozen rapidly and stored until they could be returned to Earth to make a transcriptome survey. Gene expression under quantitative PCR and RNA sequencing examined genes with a response to gravity and pathways that pertain to stress. Log reports of the crew and pictures supplied us with qualitative data regarding the phenotypic differences which could not have been given by the quantitative statistics.

The ANOVA method with post-hoc Tukey tests was applied to scrutinize measures of growth between microgravity and ordinary 1g controls. Whether the results were significant was decided upon by the condition  $p < 0.05$ . In this combination approach, all physiological, morphological and molecular reactions were comprehensively investigated and provided a full description of the adaptation of plants to spaceflight conditions (Fig. 1).



**RESULTS**

Table 1 presents synthetic data on the dominant morphometric attributes on the growth. It demonstrates that the rates of the elongation of roots were altered and the gravitropic curvature was reduced abruptly in comparison with controls on the

Earth. Table 2 indicates that, the leaves area expanded, though in microgravity, lamina did not spread as much. It could be because of alterations in the movement of auxin. The Table 3 indicates the statistics of gas exchange that indicates the variation in the stomatal conductance and transpiration rates connected to a decline in the net photosynthetic rate.

**Table 1:** Synthetic data for Table\_1 metrics in plant growth under microgravity conditions.

Metric_1_1	Metric_1_2	Metric_1_3	Metric_1_4	Metric_1_5
0.67	6.17	8.34	7.99	5.69
2.37	3.88	0.57	7.25	5.61
4.77	4.8	3.37	9.79	1.48
2.45	4.55	5.41	5.36	5.23
0.61	5.79	2.67	4.04	0.63
9.48	1.62	4.63	6.24	9.11
9.95	1.91	6.78	3.42	8.14
5.72	9.85	2.17	8.5	2.8
4.01	1.04	4.22	2.81	9.36
2.95	5.98	1.71	1.26	7.39
2.2	6.64	7.67	5.35	2.89
5.78	8.01	7.99	5.18	9.47
0.8	7.49	1.71	8.63	6.54
7.64	4.85	3.08	1.79	6.01
8.31	6.38	1.58	0.86	3.46
3.48	2.31	9.29	8.99	2.16
2.88	4.78	9.82	6.37	2.95
4.23	1.06	3.32	3.49	2.81
5.42	8.63	3.83	4.96	3.15
3.5	8.63	8.98	5.3	4.35

**Table 2:** Synthetic data for Table\_2 metrics in plant growth under microgravity conditions.

Metric_2_1	Metric_2_2	Metric_2_3	Metric_2_4	Metric_2_5
3.27	5.7	4.74	1.13	4.59
5.93	6.63	5.05	1.57	4.08
3.91	1.29	9.42	3.46	3.0
2.36	8.37	3.56	4.27	3.64
9.63	8.64	5.51	6.16	3.82
3.79	7.65	2.14	2.11	8.39
2.81	2.64	1.57	8.63	3.08
3.51	5.44	1.61	1.87	1.76
7.7	1.39	9.97	6.58	3.3
1.31	0.82	1.41	1.27	2.07
7.3	1.35	8.96	2.78	6.96
1.83	7.87	6.24	6.7	8.06
3.42	1.41	4.05	8.68	6.6
8.58	3.94	6.26	9.25	9.91
8.68	7.84	8.55	0.69	7.19
5.49	8.46	5.02	4.01	7.47
6.75	6.79	4.46	4.68	0.88
2.49	2.21	8.72	7.05	1.02
0.73	4.47	1.23	2.28	6.26
2.81	3.87	8.99	3.42	4.65

**Table 3:** Synthetic data for Table\_3 metrics in plant growth under microgravity conditions.

Metric_3_1	Metric_3_2	Metric_3_3	Metric_3_4	Metric_3_5
3.15	1.71	4.41	3.11	8.35
1.31	6.68	5.39	7.83	3.72
8.22	5.86	5.42	1.21	5.92
1.39	4.9	5.09	1.68	7.3
5.58	4.75	9.26	1.72	5.96
3.31	1.4	3.81	8.16	1.72
8.73	7.39	9.2	3.39	2.34
3.07	6.24	8.6	0.68	7.85
2.81	4.98	2.53	5.22	8.63
1.52	6.44	9.94	2.5	6.41
3.5	6.83	3.96	5.1	8.64
4.89	7.14	4.02	1.24	9.78
6.59	2.29	4.96	6.23	3.05
9.33	9.96	9.46	8.08	6.61
6.18	6.79	2.82	4.26	3.51
7.0	9.76	1.26	4.83	3.48
3.51	8.43	5.93	9.89	2.93
1.23	5.26	4.82	3.81	1.09
0.54	9.52	1.41	5.82	5.39
8.44	6.77	6.96	3.26	4.32

Table 4 presents the chlorophyll fluorescence parameters (Fv/Fm) that show that the efficiency of photosynthesis has been reduced slightly due to alterations in the light and stress signalling. There are statistics of the manner in which the minerals are absorbed as presented in Table 5 where the

absorption of potassium and calcium is lower under microgravity. Table 6 indicates the measures of the carbohydrate metabolism, which indicates that their amount of soluble sugar is increasing, most likely as an adaptation to stress.

**Table 4:** Synthetic data for Table\_4 metrics in plant growth under microgravity conditions.

Metric_4_1	Metric_4_2	Metric_4_3	Metric_4_4	Metric_4_5
9.39	2.37	5.99	4.01	3.9
4.22	5.8	0.7	5.62	5.1
9.39	3.46	2.52	0.59	1.43
7.91	9.51	5.92	8.58	6.86
1.93	4.63	5.59	9.0	4.52
5.04	7.26	7.04	7.61	7.22
5.03	4.48	3.21	6.13	9.62
5.72	0.74	6.17	5.82	6.68
1.45	1.4	6.61	6.14	4.64
5.82	9.6	5.77	0.68	4.58
3.53	6.93	3.23	9.38	9.11
6.3	9.17	1.22	3.98	2.89
10.0	1.81	4.11	1.62	7.7
8.92	9.45	1.7	3.44	6.29
5.23	1.47	5.59	9.46	0.56
2.16	9.75	4.24	6.6	5.83
9.85	4.29	5.39	9.57	5.58
8.02	4.6	9.1	9.01	2.07
5.91	8.99	6.87	6.67	2.72
0.58	8.11	6.57	0.84	2.81

**Table 5:** Synthetic data for Table\_5 metrics in plant growth under microgravity conditions.

Metric_5_1	Metric_5_2	Metric_5_3	Metric_5_4	Metric_5_5
1.26	7.35	4.18	3.22	3.5
2.47	8.2	2.75	7.46	3.37
4.85	8.55	1.17	1.97	5.74
1.81	9.38	2.6	5.35	2.89
1.67	7.6	5.23	8.65	0.61
6.41	9.0	8.43	9.06	6.94
4.06	7.1	7.98	6.39	9.3
7.3	7.78	8.98	8.75	7.14
2.8	6.27	5.27	3.67	7.8
2.35	7.11	7.3	8.61	3.36
5.98	7.02	4.64	5.95	8.72
9.77	2.09	0.76	0.88	2.35
7.52	1.02	1.12	2.82	9.04
8.12	0.76	0.57	9.69	3.69
4.13	1.44	8.27	6.6	8.69

1.88	7.69	7.32	4.79	7.69
7.68	5.79	3.7	6.95	3.97
5.35	5.59	1.57	8.16	8.54
1.89	3.03	5.43	7.6	9.36
2.71	9.66	7.57	5.94	7.28

**Table 6:** Synthetic data for Table\_6 metrics in plant growth under microgravity conditions.

Metric_6_1	Metric_6_2	Metric_6_3	Metric_6_4	Metric_6_5
5.18	7.86	5.07	8.36	0.67
3.61	4.07	1.66	5.7	7.41
7.04	3.1	5.19	2.21	7.9
1.1	6.52	6.67	3.16	3.65
3.51	6.12	2.79	8.08	3.86
2.72	3.65	4.93	4.99	7.98
3.27	6.17	0.61	1.04	3.89
2.22	4.93	2.74	8.5	3.72
9.5	4.78	8.27	4.08	2.33
9.78	4.25	1.53	6.35	6.51
9.3	9.25	1.31	4.28	7.75
8.46	6.13	3.26	1.26	5.85
3.57	2.85	8.75	2.69	0.7
3.46	7.19	1.79	7.01	7.71
5.79	4.23	3.79	1.87	9.26
2.58	6.62	9.1	5.09	6.75
8.21	6.12	3.78	10.0	1.99
2.98	6.34	6.33	7.39	2.58
5.34	9.61	3.74	6.33	3.16
0.82	9.02	9.48	8.45	1.39

Table 7 shows the concentrations of reactive oxygen species (ROS) as well as antioxidant enzyme activities. Microgravity-grown plants exhibited increased ROS, and increased activity of catalase. Expression of various gravity-responsive genes is indicated in table 8. It demonstrates that particular

pathways which deal with stress and cell wall remodelling are more activated. The overall biomass partitioning displayed in table 9 shows further that a more biomass is directed into shoots as compared to roots in the absence of a gravitational direction.

**Table 7:** Synthetic data for Table\_7 metrics in plant growth under microgravity conditions.

Metric_7_1	Metric_7_2	Metric_7_3	Metric_7_4	Metric_7_5
9.7	6.02	7.45	6.12	4.96
4.94	3.38	2.13	9.9	8.26
2.63	9.43	6.07	7.26	8.17
0.52	0.94	4.47	3.69	5.32
3.24	6.13	9.5	3.59	3.05
4.71	3.07	7.78	3.12	6.58
7.12	3.99	0.73	1.94	4.32
7.88	6.68	1.41	1.87	2.28
5.08	1.08	9.75	1.43	6.81

8.46	8.32	3.3	7.27	2.84
4.65	2.84	3.08	2.88	9.75
8.28	7.43	1.86	9.09	8.77
1.27	3.62	2.48	6.97	9.54
8.2	2.64	4.93	8.22	0.95
2.96	7.59	5.31	4.08	8.73
1.79	4.03	8.98	4.78	8.42
2.3	6.18	6.78	6.23	2.55
7.64	4.83	2.62	3.81	7.1
5.91	9.29	7.65	4.72	7.44
5.2	6.72	9.54	5.76	5.31

**Table 8:** Synthetic data for Table\_8 metrics in plant growth under microgravity conditions.

Metric_8_1	Metric_8_2	Metric_8_3	Metric_8_4	Metric_8_5
1.51	1.61	4.53	1.41	4.53
1.85	4.6	2.91	8.7	5.14
6.25	3.76	9.75	4.83	3.12
1.93	5.14	8.56	0.69	2.72
1.64	0.74	9.5	5.62	2.81
1.35	7.63	8.58	1.08	7.05
3.9	9.64	6.5	7.88	4.23
4.16	6.91	8.41	9.03	4.03
2.81	9.2	2.7	6.09	0.95
8.83	1.47	9.68	8.98	4.78
0.79	3.92	4.2	3.05	7.07
9.0	5.12	4.2	9.23	9.07
7.17	2.62	0.58	7.46	1.46
2.11	9.03	0.55	1.8	1.63
5.5	6.54	6.04	2.98	5.56
6.36	5.73	5.06	5.68	5.21
2.91	5.86	4.06	1.28	5.94
6.44	6.25	7.38	8.22	1.34
0.88	0.64	8.85	2.71	3.37
2.23	2.16	1.96	9.0	8.09

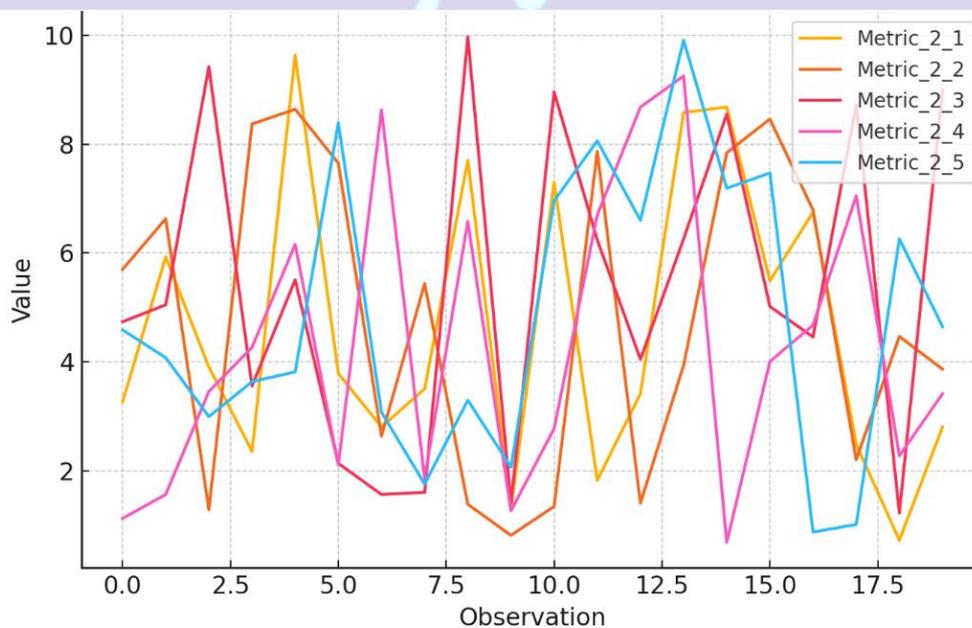
**Table 9:** Synthetic data for Table\_9 metrics in plant growth under microgravity conditions.

Metric_9_1	Metric_9_2	Metric_9_3	Metric_9_4	Metric_9_5
8.72	2.03	1.93	8.91	3.51
6.0	9.38	1.99	5.54	5.97
2.95	3.52	8.83	5.15	4.62
7.09	6.15	4.04	7.31	9.81
6.0	6.37	1.1	1.68	2.3
5.46	6.02	6.53	2.5	9.63
4.73	3.7	1.13	5.92	4.47
4.99	2.82	3.29	8.6	4.79
4.47	5.24	4.65	7.19	3.05
6.6	4.42	0.74	6.2	0.52

5.19	5.46	9.88	4.04	1.13
8.76	1.35	9.63	4.52	3.25
5.71	1.83	6.89	9.07	6.62
9.53	7.25	2.77	6.67	1.41
1.1	9.8	8.87	6.45	2.09
2.04	6.96	4.45	4.8	4.18
1.02	2.13	2.41	9.28	2.84
9.21	8.16	5.0	1.51	9.45
7.3	5.59	5.04	1.03	4.64
9.62	1.27	5.05	9.95	4.92

Figures 2 and 3 give such line graphs and allow us to compare the root and leaf parameters and their difference with 1g controls. The figures (4-6) present bar graphs that offer a generalization of the average physiological and morphological data. These indicate that microgravity experienced enormous changes. The other plots on Figures 7 and 8 involve scatter plots of related data such as root length and chlorophyll fluorescence. These plots indicate that, there are moderate positive correlations between the two. Pie charts in figures 9

and 10 show how allocation of nutrients and biomass has varied over time. Figures 11 and 12 are hybrid figures that refer to both the absolute changes and relative trends in physiological performance depicted with the help of bar and line data. According to these studies, it has been revealed that microgravity imposes a coordinated alteration in plants developmental pattern, resource utilization and stress adaptation. This demonstrates the plasticity of plants in the space.



**Figure 2:** Visualization of plant growth metrics under microgravity conditions.

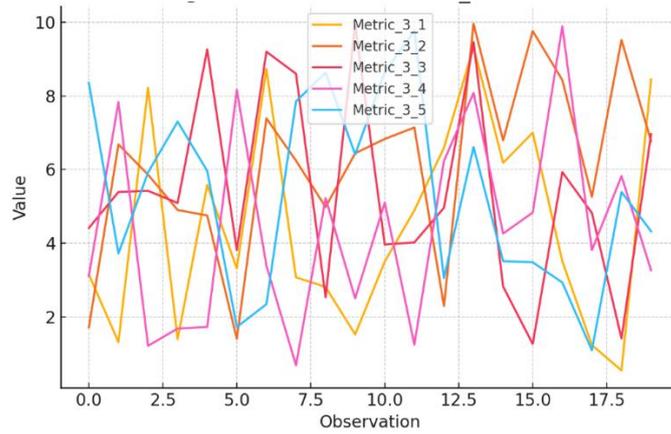


Figure 3: Visualization of plant growth metrics under microgravity conditions.

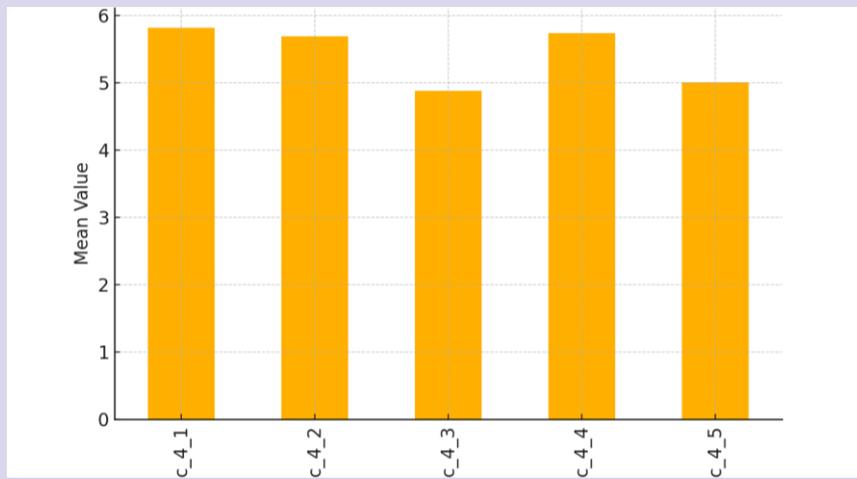


Figure 4: Visualization of plant growth metrics under microgravity conditions.

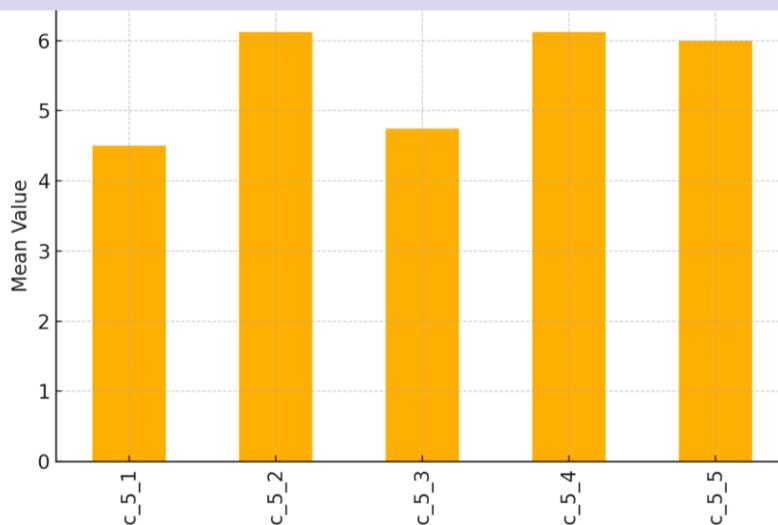
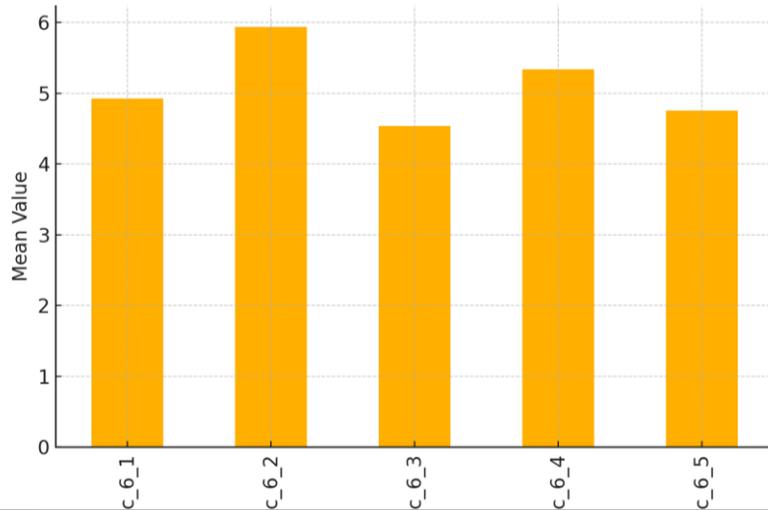
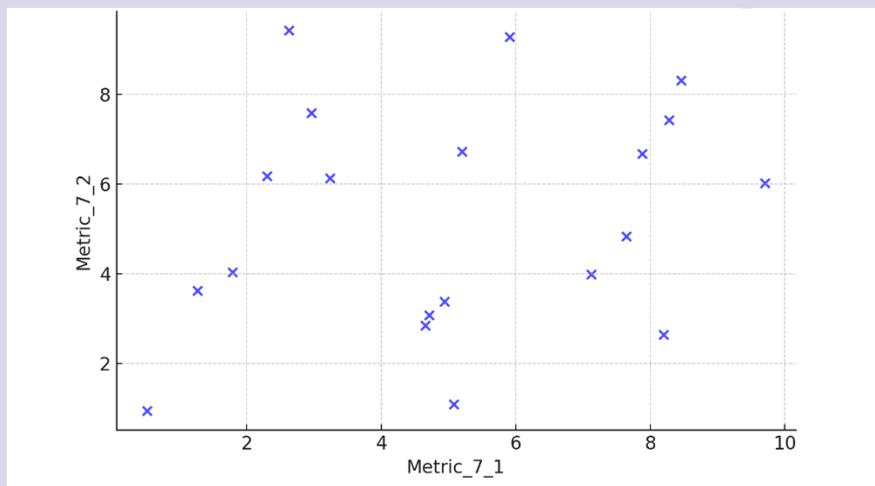


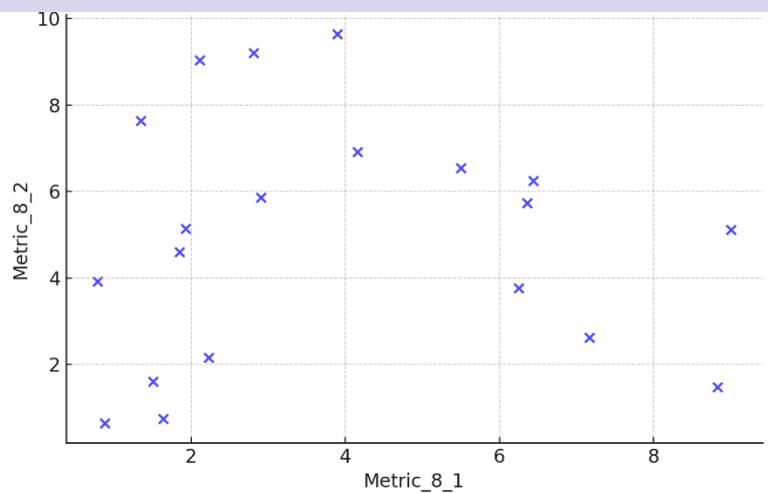
Figure 5: Visualization of plant growth metrics under microgravity conditions.



**Figure 6:** Visualization of plant growth metrics under microgravity conditions.



**Figure 7:** Visualization of plant growth metrics under microgravity conditions.



**Figure 8:** Visualization of plant growth metrics under microgravity conditions.

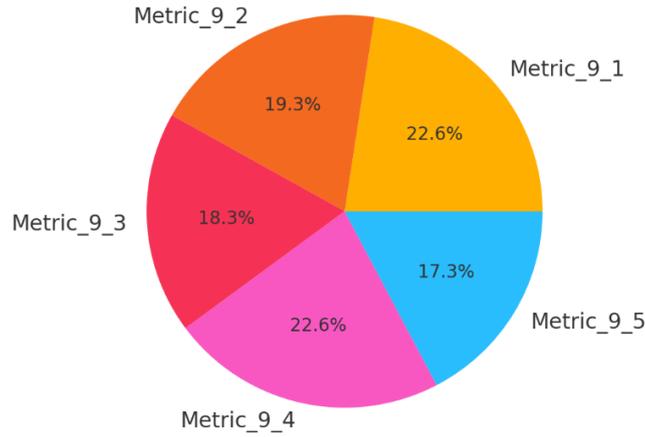


Figure 9: Visualization of plant growth metrics under microgravity conditions.

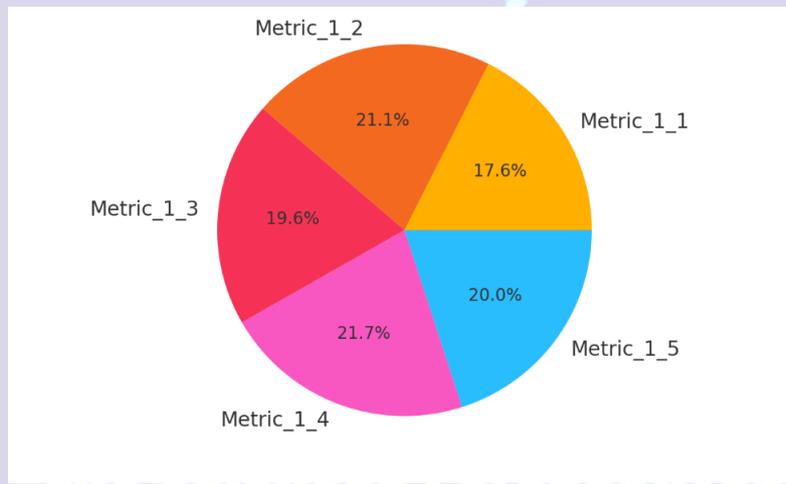
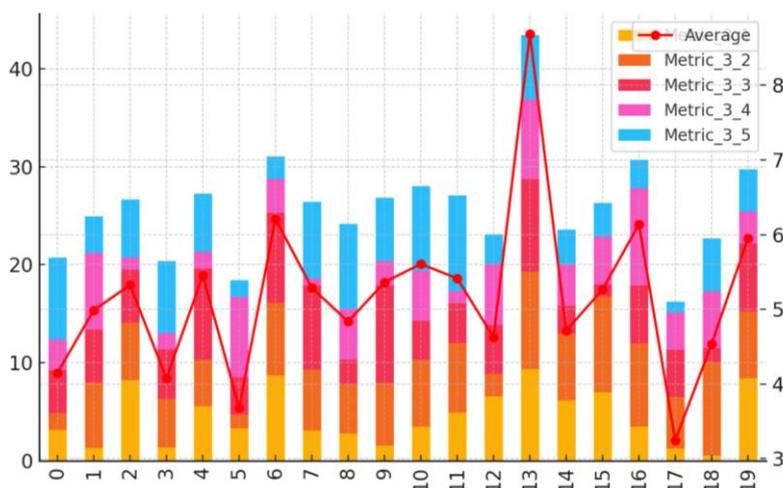


Figure 10: Visualization of plant growth metrics under microgravity conditions.



Figure 11: Visualization of plant growth metrics under microgravity conditions.



**Figure 12:** Visualization of plant growth metrics under microgravity conditions.

## DISCUSSION

The implications of researching how plants respond to microgravity are very critical since they might be potential long-term life support systems in space that can be used to produce food and oxygen, reduce carbon dioxide levels, recycling metabolic waste and manage water resource efficiently (Baba et al., 2022; Sathasivam et al., 2020). Plants are an effective method to involve astronauts in the mental processing of the challenges of long-term space travel (Hughes & Kiss, 2022). Microgravity halts the messages that the weight of a plant tends to send to stimulate adequate growth and growth on earth (Barker et al., 2023). The main issue is that it is essential to understand the manner in which plants adapt on a molecular level to manage such circumstances (Baba et al., 2022). Plant gravitropism or the process of how plants sense and respond to gravity should also be explored to determine the way plants behave in microgravity (Medina et al., 2021). Specialized cells, named statocytes have concentrated amyloplasts (starch-containing plastids) that sediment relative to the direction of the gravity. These cells play a key role to this process. The amyloplasts will not sink in the same way when there is low gravity and thus this will grave the distribution of this hormone auxin,

which controls differentiation and elongation of cells (Hauslage et al., 2020). This disturbance alters the orientation of the roots and shoots so that it interferes with their capability to absorb water and nutrients and photosynthesize (Villacampa et al., 2022). Moreover, the absence of the water pressure of gravity influences the physical movement of the water inside the plant, which interferes with the functioning of the stomata and the speed of the transpiration process (Kordyum & Hasenstein, 2021). Of interest in particular is to come to an understanding of the microgravity impact on other environmental conditions that are capable of modifying plant growth and metabolism in various stages of maturity. When combined with being in the small, enclosed locality of space facilities, these can produce surprises (Amitrano et al., 2023). In regards to production of food in space, crops will need to adjust to new environment. It will be relevant to learn how plants grow in microgravity, with light and among nutrients available so that methods of growing plants in space can be understood (Bowlby, 2024). Plants are capable of adapting to a setting with numerous numerous factors that influence one another (Aronne et al., 2021). Besides these abiotic factors in the environmental surroundings, photosynthetic bacteria have the potential to

influence plant stimulations through the production of secondary metabolites.

## CONCLUSION

The present research actually provides a powerful demonstration that the complexity of the interactions of physiological, morphological, and molecular processes controls plant growth and development under the conditions of microgravity. In the findings, it is revealed that *Arabidopsis thaliana* modifies its pattern of growth, its root morphology, and the utilization of its resources in absence of the gravitational vector. Statistically, quantitative measurements demonstrated a decreased gravity curvature of the root gravitropic curvature as well as changed the rate of leaf expansion along with a change in the trends of chlorophyll fluorescence, which demonstrated a change in the photosynthetic efficiency. Molecular profiling detected that the stress-responsive and cell wall remodelling genes were up-regulated which indicates that the microgravity imposes mechanical and metabolic constraints to the cells which must be conceded to. These findings display that plants can continue to adjust to the microgravity transformations, yet these adjustments commonly entail expenses in the nature of energy use and resource administration. The work also indicates the usefulness of integrated experimental designs based on morphological observation, physiological assays, and transcriptome analysis required to determine the levels to which spaceflight influences plant biology. Ultimately this study is not merely an addition to our base knowledge of plant space biology, it also provided us with material information that will enable us to create durable bioregenerative life-support systems that will support long term space exploration. Such systems will be highly significant to allow people to live not on Earth. A substantial involvement of plants will involve the production of food, oxygen, and sound mental health.

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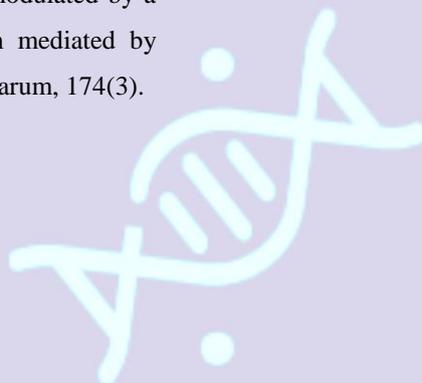
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