INFLUENCE OF THE COSMIC RADIATION AND THE GRAVITATIONAL EFFECT OVER PLANT GERMINATION IN OUTER SPACE

[1]

Colegio Huerta de la cruz (Algeciras)

Juan A. Prieto Sánchez

María Pilar Orozco Sáenz

[1] Image from: How to grow crops on Mars if we are to live on the red planet

Introduction

Not so long ago, the possibility of surviving several months in outer space was simply science fiction. During the last 50 years technology has advanced greatly. Nowadays, during their missions, astronauts spend longer periods of time orbiting the Earth in the International Space Station (ISS) and the possibility of crewed missions to Mars does not seem like a dream anymore.

However, this will not be possible without providing astronauts on the one hand with the technology to easy their stay in a spacecraft and on the other hand with self sustainable systems capable of maintaining life outside Earth.

This is why studying plants' growth under conditions different from Earth is tremendously important. Plants are essential since they could absorb CO_2, produce oxygen, fresh water and fresh food to the astronauts and also a more familiar environment. Furthermore, this kind of scientific knowledge could also contribute to improve the agricultural methods currently used.

There are two factors that can affect plant growth in outer space: cosmic rays and gravity. We have investigated the effects of microwaves, X-rays and UV radiations on plant germination. Similarly, we have studied plant behavior under hypergravity and microgravity.

Objectives

- Study plant growth under circumstances other than Earth's
- Study the effect of cosmic radiation on seeds
- Introduce (continue) the study of astrobiology in secondary school

Secondary objetives

- Stimulate creativity and imagination in secondary school students.
- Develop the abilities that define scientific research.
- Understand the importance of critical thinking in every aspect of life.

COSMIC RADIATIONS

Every visible object in the universe emits some sort of radiation. This energy moves throughout space. Scientists believe that there are two types of radiation: electromagnetic radiation and cosmic radiation.

Electromagnetic radiation

It consists of electromagnetic waves that travel at light speed. It is composed by radio waves, microwaves, infrared (heat), visible spectrum, UV light, X-rays and gamma

rays.

Our atmosphere protects us from some highly energetic electromagnetic radiation: gamma rays and some UV light, otherwise life could not be possible on Earth.

Cosmic radiation

Cosmic radiation is the name given to some highly energetic atomic particles that travel through space. Their level of energy is related to their speed. Their frequency of about 160,2 GHz, belongs to the microwave range. It corresponds to 1,9mm wavelength. Cosmic radiation is also known as cosmic microwave background radiation and it is one of the most solid evidence of the Big Bang theory.

Cosmic radiation can have different origins:

- Cosmic rays: they are the particles with the highest energy content. They appear from every direction. Their origin is unknown although it could be generated by supernovas, binary stars systems or the centre of galaxies.

- The sun: it emits electrons and protons, particles with high energy, through some phenomena such as solar wind, solar coronal mass ejections and solar eruptions.

- Radiation belts: they are particles trapped by the Earth magnetic field and although their energy is lower than the particles described above, they can cause great damage to artificial satellites due to their high concentration. These particles are also known as Van Allen radiation belt.

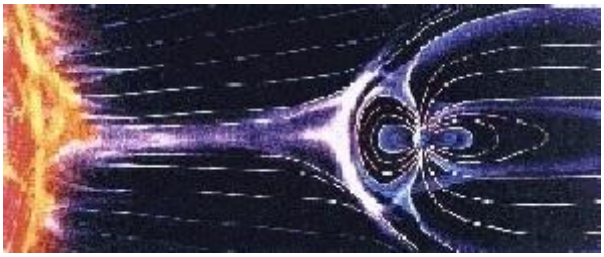


Image 1. Artistic representation of the solar wind influence over the Earth magnetic field. [2]

Due to its high energy, cosmic radiation can negatively affect living organisms. The Earth magnetic field protects living organisms from cosmic radiations by deviating them away from the surface of the planet. Occasionally, some charged particles enter the upper atmosphere through the poles producing auroras.

[2] Image from http://srag-nt.jsc.nasa.gov/SpaceRadiation/What/What.cfm

1 STUDIES OF THE EFFECTS OF MICROWAVE RADIATION

In the course of our project chickpea and bean seeds were submitted to microwave radiation. To do so, seeds were divided into two groups. The first group of seeds was irradiated and later rehydrated while the second group was first rehydrated and then irradiated. A 1250W home appliance was used. Seeds were exposed to microwave radiation for 10s, 15s and 30s. The percentage of germination was studied.

Register table

Table 1. Germination percentage of seeds exposed to mw

	Germination Percentage			
Time		10s	15s	30s
Chickpeas	Hydrated seeds	0	0	0
	Dried seeds	60	70	0
Beans	Hydrated seeds	20	30	0
	Dried seeds	40	70	30

Conclusions

Chickpeas showed the best germination rate. On the other hand, as expected, wet seeds put up with radiation worse than dried seeds.

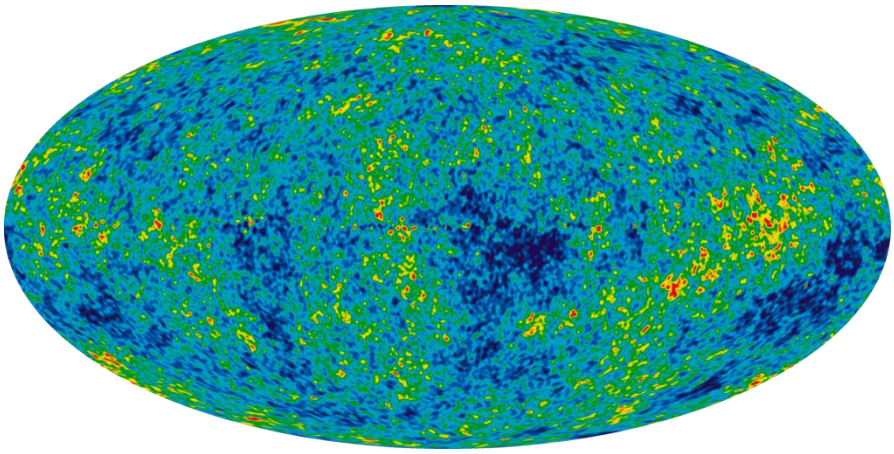
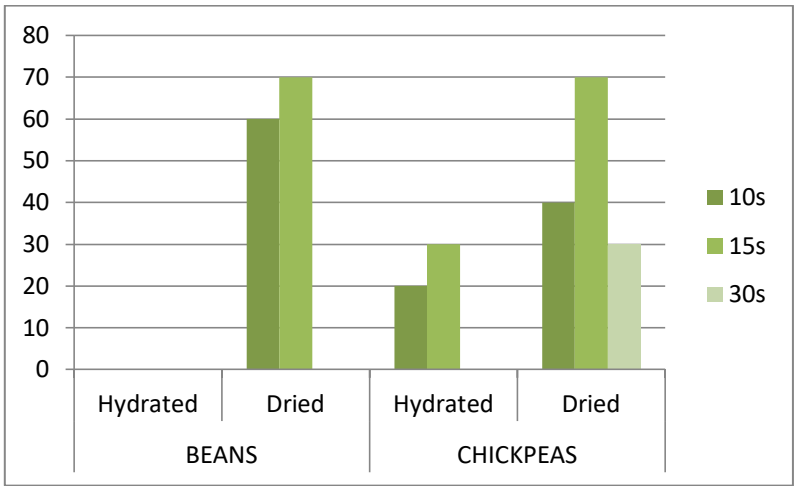


Image 2. Cosmic microwave background radiation. NASA / WMAP ScienceTeam

This is because polar molecules (water) present in the seeds try to line up with the electromagnetic field and in doing so produce friction and therefore heat. On the other hand, ions in the seeds (salts) tend to move in the electromagnetic field (positive ions to one side and negative ions to the other) producing even more clashes, friction and heat.

Graph 1. Germination percentage of seeds exposed to mw



Results have to be analysed in two different ways according to the water content of the seeds.

When seeds are hydrated, their water content induces them to heat up. This causes protein denaturation and as a consequence hinders germination at short exposure times and precludes germination with long periods of exposure.

Surprisingly, when seeds were exposed to short periods of microwave radiation the germination and the growth of the plants were stimulated. This effect had been previously described in different species such as bell and chilli peppers *Capsicum annuum L.* (Alexander Álvarez *et all.* from Instituto de Investigaciones Agropecuarias in Bayamo, Cuba).

Another effect observed was that short periods of radiation accelerate the process of germination when compared with seeds that had not been exposed (control).

Table 2. Time for percentage of seeds exposed to mw

Time for germination (days)				
	Type of seed	10s	15s	30s
Chickpeas	Control seeds	4	5	0
	Dry seeds	3	4	0
Beans	Control seeds	5	6	0
	Dry seeds	4	4	4

Our data are in agreement with studies carried out by other research groups. Unfortunately, we have not been able to perform a statistic analysis of our data simply because our facilities are not big enough to take in the minimum number of repetitions required.

Other effects of microwaves on plants have been described

- Calcium and sulphur depreciation in peas.
- Chromosome abnormalities in wheat.
- Resin production increment in pine trees.

2 STUDIES OF THE EFFECTS OF UV RADIATION

Ultraviolet light (UV) is the electromagnetic energy emitted from 400 nm and 15 nm approximately. This light is invisible to human eye. It commonly comes from the Sun. There are several types of UV radiation depending on the wave length.

In order to study the effects of UV rays over the germination of seeds we irradiated dried and hydrated seeds with a 25W lamp for 45min. Data are shown in the table below.

Register table

Table 3. Germination percentage of seeds irradiated with UV light

Germination Percentage		
Chickpeas	Hydrated seeds Dried seeds	70 100
Beans	Hydrated seeds Dried seeds	0 0

Conclusions

None of the bean seeds exposed to UV light could germinate. However, some of the chickpea seeds did, particularly the dried seeds.

We found these results to be surprising. Perhaps the lamp was not powerful enough or the time of exposure was not long enough. UV radiation is so energetic that provokes breaking off in atoms and molecules and, as a consequence, the formation of ions. UV irradiation also alters the genetic material of cells causing their deterioration. In humans, a prolonged exposure to UV light is related to skin cancer.

Studies on plant exposure to UV light also showed the following effects:

- Short stems and branch production due to phytohormones oxidation.
- Small leaves due to the inhibition of cell division.
- Increment of wax content on the cuticle and changes in its composition.
- Decrement in the number and alterations in chloroplasts.

3 STUDIES OF THE EFFECTS OF X-RAYS

X-rays are a type of high-energy electromagnetic radiation. Most X-rays have a wavelength ranging from 10 to 0,01 nanometres. There are invisible to the human eye.

During our experiment seeds were exposed to X-rays (100kUp and 320mAs) for 3200 ms. The results are shown in the table as follows.

Image 3. Seeds being exposed to X-rays

Register table

Table 4. Germination percentage of seeds exposed to X-rays

Germination Percentage		
Chickpeas	Hydrated seeds Dried seeds	0 50
Beans	Hydrated seeds Dried seeds	0 100

Conclusions

The effects of X-rays on living organisms depend on the exposure period. In general, short periods of exposure to X-rays are not harmful. However, longer periods can cause severe damage by breaking the hydrogen bonds between the bases and therefore altering the DNA structure.

However, some authors have described a stimulating reaction in the growth of the Californian Wonder pepper. When irradiating seeds at 5, 10, 20 and 30 G, with a low power X-rays equipment (11,47 Gy/min) results revelled a significant increment in the height of the plants, length of the root, diameter of the stem, average weight of the fruit and fruit yield when compared with non irradiated plants used as a control.

This stimulating effect could be explained by taking into account the excitation produced by the ionizing radiations on the seeds, which provokes metabolism stimulation and favours the growth and the development of the plants.
In addition, ionizing radiations favour the synthesis of a particular kind of organic peroxide which, at low concentrations, stimulates the general metabolism of the plant.

GEOTROPISM

Geotropism is the growth of the parts of plants in response to the force of gravity. The upward growth of plant shoots is called negative geotropism while the downward growth of roots is positive geotropism. This orientation is particularly important during the germination of seeds. Any alteration of this guided growth could result in plant malfunction since roots must enter into the soil to absorb water and minerals; while stems and leaves must grow against gravity so as to get as much light as possible in order to carry out photosynthesis.

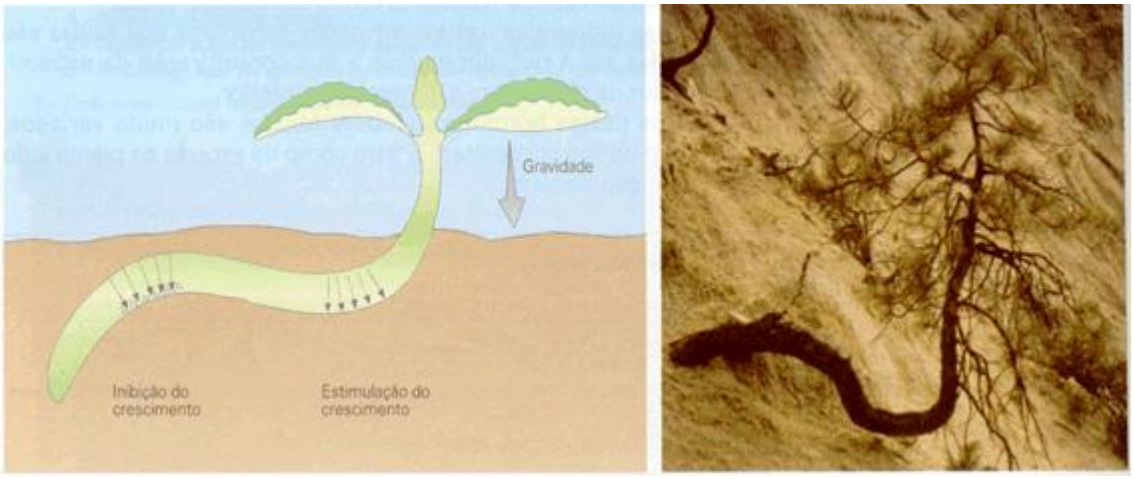


Image 4. Geotropism[3]

In order to investigate the effects of gravity on the germination of seeds, gravity conditions were altered during our investigation in two different ways:
Increasing gravity: hypergravity
Decreasing gravity: microgravity or weightlessness

1 STUDIES OF THE EFFECTS OF HYPERGRAVITY

Hypergravity can be defined as the condition by which a gravity force is increased and exceeds that on the surface of the Earth. This is expressed as greater than 1g.

[3] Images obtained from:
https://www.sobiologia.com.br/conteudos/Morfofisiologia_vegetal/morfovegetal35.php

We decided to submit our seeds to hypergravity conditions because it is our understanding that some planets of the solar system have a gravity force greater than on the Earth and it would be interesting to understand plant behaviour under those circumstances. But that is not the only reason. In order to transport seeds outside our atmosphere, spacecrafts have to overcome gravity and therefore their acceleration provokes that all organisms onboard to stand gravity above 1g.

To simulate hypergravity conditions a washing machine was used.

Image 5. Washing machine[3] used in our study

A gravitational field was artificially created by making the washing machine to spin steadily. The gravitational force was calculated using the formula as follows:

$$a_c = g' = \frac{v^2}{r} = \omega^2 . r$$

The response to hypergravity was measured by inserting several small plastic bags into the drum. The bags contained dried bean and chickpea seeds. In addition, some of the bags also contained soil while others did not. The bag´s arrangement can be seen in the following image.

Image 6. Seeds inserted inside the washing machine

Seeds were left spinning at 1200rpm for 24h. This period of time was chosen because it greatly exceeds the time that takes for a spaceship (8 ½ min) to become weightless. In these conditions seeds experienced 80 to 300 times de force of gravity.

The results are displayed in the table as follows.

Table 5. Germination percentage of seeds exposed to hypergravity

Hypergravity germination percentage		
Chickpeas	Seeds with soil	60
	Seeds without soil	100
Beans	Seeds with soil	100
	Seeds without soil	100

Conclusions

Although the conditions simulated during the experiment were harder than those that hypothetically seeds would have suffered in a spaceship, our data showed that 24h in hypergravity does not affect the germination of seeds.

2 STUDIES OF THE EFFECTS OF MICROGRAVITY

The term microgravity refers to the state in which the force of gravity is reduced. This does not mean that gravity is not having any effect on an object. On the contrary, gravity is simply attenuated by other forces.
This is the sensation that astronauts experience whilst orbiting the Earth, not because there is no gravity but because the spaceship is moving in free fall. Objects and people can free-fall in a capsule that itself, while not necessarily in free fall, is accelerated as in free fall.
In a spacecraft orbiting the Earth, the centrifugal force compensates gravity ie. it is in free fall although it would never reach the surface of the planet unless its velocity diminishes.

Image 7. *Alien* plants [4]

[4] Taken from https://eljardindemendel.wordpress.com/2018/01/24/las-plantas-alienigenas/

In our experiment gravity was counteracted by immersing the seeds, after wrapping them with clean film, in liquids with different densities. Therefore, seeds were exposed to pulling forces of different intensities, and thus left for three months. The liquids used were water, olive oil, shampoo and shower gel.
When this time was up, seeds were divided into two groups. The first group was planted and the second group was rehydrated and later immersed again into the liquids in order to observe the plant's growth.
As previously, the study was carried out with both dried and hydrated seeds.

Image 8. Seeds in microgravity

None of the hydrated seeds germinated during the time they were submerged in the flasks. Furthermore, lack of oxygen resulted in seed fermentation and therefore, the germinatives cells were destroyed. As a consequence, the investigation continued solely with the dried seeds.

Another problem that we encountered during the experimental phase of the project was that some of the liquids entered the bags where the seeds were placed, resulting in the death of the seeds. As a consequence, the number of seeds used was smaller than in previous experiments.

Results are shown in the following table.

Table 6. Germination percentage of seeds exposed to microgravity

Germination percentage under microgravity					
		Water	Olive oil	Shower gel	Shampoo
Chickpeas	Seeds in soil	--	--	--	--
	Seeds in microgravity	0	0	0	0
Beans	Seeds in soil	--	--	--	60
	Seeds in microgravity	0	0	0	--

Seeds submerged in shampoo were the only ones that were able to germinate, and although it is just one set of data, this could reveal that microgravity has no effect on the seeds.

Conclusions

In plants, microgravity can impede water absorption through the roots and sap transport through the phloem. Furthermore, in order to allow photosynthesis water and mineral salts must be taken upwards where there the light is. Under microgravity there is not “up” or “down”.

In space, experiments have shown that plants get disorientated. Due to microgravity growth references are lost so stems and roots loose direction. A new research line could be substitute gravity with another stimulus such as light for instance.

Planting methods

Planting was done in separate boxes according to the conditions applied to the seeds. We followed a double-entry table system similar to the ones used in mathematics as to enable us to compare and monitor the plant’s progress.

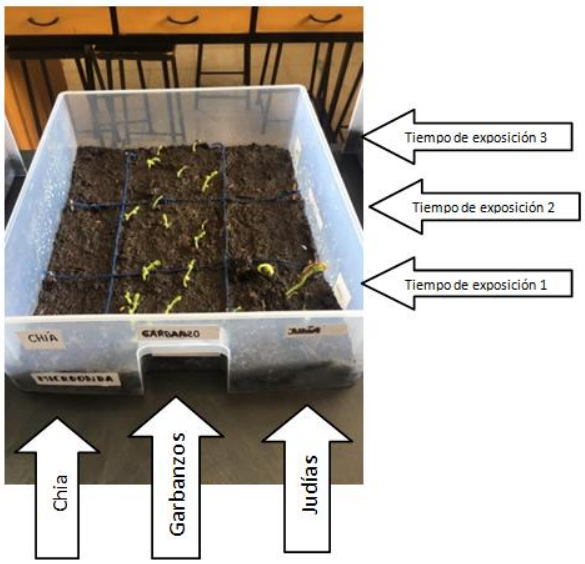


Image 9. “Double-entry cultures”

All the boxes were kept in the school lab and were watered regularly. The first few days after planting, the boxes were covered with clean film as to maintain humidity and heat. After germination, the boxes were rotated for the plants not to bend towards the light.

Image 10. Planting sequence

Outreach events

- *XI Science Fair Bezmiliana* in Rincón de la Victoria (Málaga, Spain). We were allocated in four stands.

Image 11. Science fair Bezmiliana (Málaga)

- *XIII International Forum "Science in the Streets: Diverciencia"* in Algeciras. Our project was presented in front of more than twenty secondary schools.

Image 12. "*Diverciencia*: Science in the streets" XIII Edition

And through the Agora stage at *Diverciencia*, the project was presented to the general public.

Image 13. Agora stage at *Diverciencia*

References

Cosmic radiation
https://www.astromia.com/universo/radiacioncosmica.htm

https://www.ecured.cu/Radiación_cósmica

How does a microwave work?
https://hueleaquimica.wordpress.com/.../como-funciona-un-aparato...

X- rays
https://es.wikipedia.org/wiki/Rayos_X

UV radiation
https://www.ecured.cu/Radiación_ultravioleta

https://www.fisicaenlinea.com/11energia/energia11-ultravioleta.html

Effect of UV radiation on seeds
www.scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864

Radiation and plant physiology
https://www.slideshare.net/.../fisiologa-de-las-plantas-frente-a-la-rad

An European experiment to grow plants in space in the ISS
https://www.esa.int/.../Un_experimento_europeo_en_la_ISS

Space missions
Ask the Mission Team - Question and Answer Session - NASA
https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts121/launch/qa-leinbach.html