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A STUDY OF THE EFFECTS OF MICRO-GRAVITY ON SEED GERMINATION

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ABSTRACT

This study will identify characteristics of seed germination dependent upon gravity. To accomplish this objective, four different seed types will be germinated in space and then be compared to a control group germinated on Earth. Both the experimental and control groups will be analyzed on the cellular level for the size of cells, structural anomalies, and gravitational effects. The experiment will be conducted in a Get Away Special Canister (GAS Can #608) owned by the U.S. Space and Rocket Center and designed for students. The GAS Can will remain in the cargo bay of the Space Shuttle with minimal astronaut interaction.

INTRODUCTION

The main purpose of this study is to advance the understanding of methods of agriculture in space. In the future, such methods will be required for extended space flights to Mars or for long duration space station habitation because space vehicles may not be capable of carrying all of the food necessary for these trips. By expanding the breadth of knowledge on plant growth in space, such space exploration will be more feasible.

The study focuses primarily on seed germination in space, and it will identify characteristics of germination dependent upon gravity. To accomplish this objective, four different seed types will be germinated in space and then be compared to a control group germinated on Earth. The seeds have been chosen because of their high germination rates in absolute darkness and because of their relatively small size. All four of the seeds were determined to have an optimum germination temperature range between 292 and 297 Kelvin (19 and 24 degrees Celsius). Both the experimental and control groups will be analyzed on the cellular level for size of cells, structural anomalies, and gravitropic effects.

The space germination phase of this experiment will be conducted in GAS Can #608, designated for use by students of the U.S. Space Camp. This experiment will take up roughly one fourth of the can. The GAS Can will remain in the cargo bay of the Space Shuttle with minimal astronaut interaction. The germinating seeds will be contained in a heated and insulated germination chamber in the GAS Can. This project has been facilitated by the implementation of the previously used germination chamber (which flew in GAS Can #007) of Guy Smith at the University of Alabama in Huntsville. Due to insufficient heating and insulation, his seeds froze unexpectantly during their germination period in space. The modified version of the chamber, which will be used for this study, incorporates heating mats and foam board insulation calculated to assure the survival of the germinating seeds.

In the growth chamber, the seeds will lay between layers of filter paper employed for maintaining a moist environment and for maintaining the physical orientation of the seeds before, during, and after the Shuttle flight. For the in-flight germination, the filter papers will be wetted with de-oxified water containing a trace of a triple-20 fertilizer to establish a favorable osmotic gradient across the outer coats of the seeds. After the germination period has elapsed, the chamber will be filled with a formaldehyde solution to preserve the seeds for analysis after the flight. The in-flight temperature profile of the germination chamber will be monitored, maintained between 293 and 295 Kelvin (20 and 22 degrees Celsius), and recorded for later evaluation.

The seeds in the control group on Earth will be placed between layers of filter paper in the same growth chamber that will have been used for germinating the seeds in space. The control group will be germinated as soon after the mission as possible. The temperature of the control group will coincide with those temperatures recorded during the flight of the seeds germinated in space. The control group will also be preserved with formaldehyde.

Once the experimental and control groups of germinated seeds have been generated, the seeds will be compared by size, cell structure and gravitropic effects. With the results of this experiment, the understanding and feasibility of germinating food in space should be enhanced. Hopefully, this information will benefit space endeavors.

BACKGROUND ON GERMINATION

Germination is the process by which a seed, in its preliminary stages, begins to grow when the vital conditions are achieved. At first, a seed is called "spontaneously dormant," meaning it will not germinate unless some conditions; such as--an adequate supply of water, presence of air, temperature, exposure to light, and the planting depth of the seed--are met. If one of these requirements is not met, the seed will most surely not germinate.

The two types of germination processes are epigeal and hypogeal. An epigeal germination is the process by which the cotyledons come above the surface of the soil and function as leaves. It then begins photosynthesis. In a hypogeal germination, the cotyledons stay below the surface of the soil, never come out of the testa (seed coat), and do not function as leaves.

In many germination processes of various types of seeds, hormones are present that help trigger the germination process. They are gibberellin, cytokinin, and auxin. The gibberellin is actually made by the embryo; its objective is to convert the food of the endosperm to solid substances and to take it back to the embryo. The cytokinin and auxin deal with the cell division and growth.

Going even deeper into the germination process, different parts of a plant have different functions. First, the body of the plant is called the stem. The stem's function is to support the weight of the leaves and to keep them in place against the environment. The stem has to hold up against the wind and rain. The stem is also used as a food track from the top to bottom of the plant. It contains a xylem, which is a controller of water and minerals, and a phloem, which is a controller of food from the leaves. The stem and the leaves make the food by a process known as photosynthesis. It starts at the leaves where the food is made in the chloroplasts and carried through the veins in the leaves to the stem. From there, the food moves down the phloem to the root section. This way, the whole plant is nourished. The plant uses the food it needs and then stores the rest of it in the roots.

The leaves are the next major part in the body of the plant. Their main function is to undergo photosynthesis. The leaf's structure is very delicate; it is thin and porous, allowing it to absorb light and water. The chlorophyll (the green coloring in the plant) does not stay in the leaves. It, like the food, goes to the rest of the plant. The leaves on a plant are arranged in a spiral pattern from top to bottom. Located on these leaves are leucoplasts, where the food is made for the plant.

Finally, there is the root section of the plant's structure. The root's primary objective is to anchor the plant in the ground and to draw nutrients and water from the soil for the nourishment of the plant. The roots also store food for later use.

Below (Figure 1) is a diagram of a cross-section of a bean.

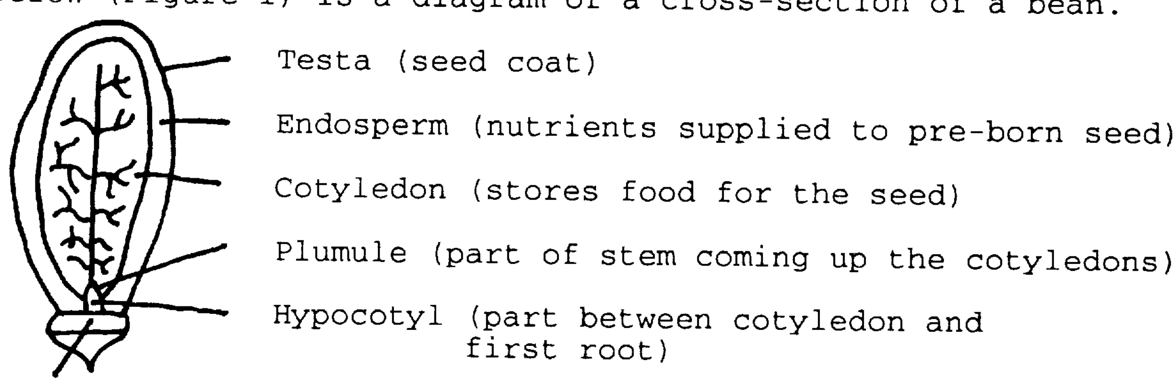

Figure 1. The location of tissues in a bean seed.

FEASIBILITY STATEMENT

In the future, we will have astronauts living in space for long periods of time to do experiments, study the earth, other planets, the sun, other solar systems, or even other galaxies. We will also have astronauts living in orbits around the earth or on the moon. Growing food in space would be practical to feed the astronauts on a space voyage, for example, on a journey to Mars, or a ninety day stay on a space station. The weight of the food products that would be required for the crew to survive would be tremendous, as experiments would take up most of the weight on long space journeys. We could transport plants or seeds, support for the plants, oxygen, water, and the thirteen necessary elements[1] for the plants to survive instead of sending food already grown, into space for the astronauts. Even though most of the food on a long journey to Mars or beyond could be brought along, some food must be grown during the journey because of the great psychological needs of the crew. There has to be an effort to vary the monotony of rehydrated meals. Growing fresh vegetables can be used to vary this monotony according to Food Technology. We may, in the future, need more food for the people living on earth as the population rises. In space, we would not have to worry about soil. It would be easier to find defects in roots as the roots would be in chemicals, not in soil. Pests could be controlled easier in a controlled environment such as the space station.

There are many different ways to grow seeds in space including spinning drums making it possible for seeds and plants to grow in an artificial gravity. If there is a nuclear war, then the earth would be full of radiation and, we would have to depend on an alternative food supply--one in space. Or, if a world wide famine happens or some kind of early frost damages the crops, then we would have to turn to our emergency food supply in space. This project would be feasible to biological research in a micro-gravity environment because it would allow astronauts to make their own supply of food in space at the space station. This would reduce the cost of transporting food from Earth to space and would reduce the psychological effects on the astronauts.

Aside from the transportation costs, payload space would be saved; thus, more equipment could be transported into space on fewer shuttle flights. Since germination is the first step in a plant's development, if germination is impossible or impractical in a micro-gravity environment, then an alternate method of manufacturing food would have to be researched.

OBJECTIVES

The proposed GAS Can (Get Away Special Canister) has the following objectives:

- To successfully germinate one or more tomato, lettuce, radish or turnip seeds in a micro-gravity environment.

- To determine the approximate germination period of a tomato seed in the micro-gravity environment.

- To determine any peculiarities in the size and structure of the germinated seed.

- To determine any peculiarities in the length of germination.

- To determine the effectiveness of such an experiment for further research and use.

[1]"Hydroponics: The Land, EPCOT Center." March 1987.

- When the project returns, to study the cellular differences at the nuclear level and possible alterations in cell divisions.

TYPES OF SEEDS

In this experiment, four different types of seeds will be germinated, including tomatoes, lettuce, radishes, and turnips. Following is information on the four seed types chosen for this experiment.

Dombello Tomato Seed

Hydro-Gardens, Inc., PO Box 9707, Colorado Springs, CO (800-634-6362). The optimum temperature is 297 Kelvin (24 degrees Celsius), but it still germinates at lower temperatures. It germinates in three to five days and can be cultivated at 70 days. 85% of the seeds germinate. It is a promising hybrid since it has a wide range of resistances and fruit of excellent shape, color, quality and size. It has a compact plant habit and a good total production. The fruit is of the greenback type with a deep red color at maturity. It is resistant to tomato mosaic virus, resistant to cladosporium races A, B, C, D and E, resistant to fusarium races 1 and 2, resistant to the most occurring pathotypes of nematodes and free from silvering.

Red Sails Lettuce (E5153-8)

Park Seed Company, Cokesbury Road, Greenwood, SC 29647-0001 (800-845-3369). The optimum temperature for germination is 294 Kelvin (21 degrees Celsius). It germinates in 7 days, with a few germinating in 3 to 5 days. Approximately 90% of the seeds germinate, and the lettuce can be cultivated at 45 days. It is an AAS award winner and a high quality red lettuce. It has an excellent flavor and a high nutritional value.

Radish Charriette Hybrid (E5747-7)

Park Seed Company. The recommended temperature for germination is 19 degrees Celsius. It can be cultivated at 24 days. It is the most attractive, vigorous rooted quality eating radish available today. The roots achieve 5 cm (2 inches) in 24 days. This variety can be grown in hot and cold weather, in Spring and Fall, and in wet and dry areas with consistent performance.

Purple Top White Globe Turnip Seed (E5469-7)

Park Seed Company. The recommended temperature for germination is 19 to 20 degrees Celsius. It germinates in 5 days and can be cultivated at 57 days. This variety has round roots 12.5 to 15 cm (5 to 6 inches) in diameter with purple tops. The flesh is white, of fine grain and is sweet.

HYPOTHESIS

While germinating seeds in an experiment in which observations are to be made between an earth controlled experiment and a micro-gravity experiment, many differences can appear when a comparison is made.

1. There are many differences that might occur between the control and the micro-gravity experiment within a time span of three to five days. Some of these possible changes are:
   - size and shape of the seed while germination occurs
   - time span of the germination process
   - root size, if there are any roots
   - temperature needed for germination
   - amount of water needed for germination to occur
   - color of the stem and leaves
   - amount of leaves, if there are any leaves
   - change in whether or not a seed is a dicotyledon or a monocotyledon

2. Micro-gravity is considered to be a state in which little strain or resistance is forced upon an object, causing it to appear to be floating. This state is created by "free-fall". For example, the orbiter falls around the Earth in an elliptical orbit. It constantly falls, creating a condition in which only one-sixth of the weight of an object is recorded, thus creating micro-gravity.

   One change that may occur in the micro-gravity environment is that it will take longer for the plant to grow after the initial germination process. This would be due to the different placement of the amyloplasts. Amyloplasts detect gravity for the plant and tell it in which direction to grow. The regeneration of the root caps where the amyloplasts are found will take a much longer time due to the confusion of the amyloplasts in the strange environment. If the root caps do not regenerate at all, then the roots will contain many more vacuoles and become callous-like cells. Another possible change would be that a different amount of the chemicals needed by seeds to germinate will be required. We have not performed this experiment in micro-gravity and are unable to predict the importance of certain chemicals. This experiment will not be in space for fourteen days, so only the initial stages of germination can be observed.

EQUIPMENT

Below is a list of the equipment used in the radish seed experiment in GAS Can #007 (Figure 2).[2] Most of the same equipment is being used in the Seed Growth Experiment in GAS Can # 608. Modifications to this list are in the next section.

#	EXPERIMENT COMPONENT	QUANITY	MATERIAL(S)
1	Experiment Housing	1	2024-T3 Aluminum
2	Magnetically Coupled Gear Pump	2	316 Stainless, TFE, Graphite Micropump #P11-361-70G,
3	Growth Chamber	1	Dow Corning PLEXIGLAS
4	1/8" diameter Tubing	4'	1100 series Aluminum
5	1/8" TEE Fitting	2	316 Stainless, Swagelok #SS-200-3
6	1/8" O-Seal Straight Connector	4	316 Stainless, Swagelok #SS-200-1-OR
7	Check & Adjustable Relief Valve	2	316 Stainless, Swagelok #SS-2C-3
8	1/8" 90° Elbow Fitting	4	316 Stainless, Swagelok #SS-200-2-2
9	1/4" thick Fiberglass Board	1	Owens Corning Fiberboard
10	Ceramic Fiber Insulation	2 lbs	Kaolin (High Purity Alimina-Silica Fireclay) Thermal Corp. Cat. No. 4019-10
11	Aluminized Mylar Foil	6 sq ft	0.4 mil Mylar with Alu Coat
12	Heater	1	1000 ohm, 5 watt Resistor
13	Temperature Controller	1	Bi-element Thermal Switch set to "ON" at 19°C or below.
14	Filter Paper	20 sq in	WHATMAN #4 Qualitative Filter Paper
15	Fertilizer Solution	40 ml max	20-20-20 NPK Peter's Soluble Plant "Food", 1% concentratio
16	Buffered Formalin Solution	40 ml max	10% W/V (4% Formaldehyde) buffered to 7.0 to 7.1 @ 25°C with Sodium Acetate
17	Bladder	2	RTV Silicone Rubber
18	Temperature Sensor	1	Thermistor, Aluminum housing
19	Connector, ITT Cannon	1	CA3106R20-11S-A115
20	Connector, ITT Cannon	1	CA3102E20-11P-A95
21	Teflon Wire, Hook-up	10 ft	22 guage nickel plated, TFE
22	Gasket	5 sq in	1/16" thick RTV Silicone
23	Helicoils, Self-locking, 6-32	16	MS21209, AMS-7245C
24	Helicoils, Self-locking, 4-40	9	MS21209, AMS-7245C
25	Socket Head 4-40-1/2" Screws	33	304 Stainless
26	Socket Head 6-32-3/4" Screws	12	304 Stainless
27	Socket Head 8-32-1" Screws	4	304 Stainless
28	Counter Sink 6-32-3/8" Screws	20	304 Stainless
29	Flat Washers: #4, #6, #8, 1/4		304 Stainless
30	Lock Wire		Nickel Chrome 22 guage
31	Breakaway Wire		Copper with Gold Plate 24 gua
32	Hex 1/4"-20-1"	8	304 Stainless
33	Radish Seeds (Raphanus sativus)	30	Biological Material

Figure 2. Equipment list for use in GAS #007.

[2]Smith, Guy A. "Initial Project Report on ATHICAS." Huntsville, Alabama, n.d. (Report to Konrad K. Dannenberg at the U.S. Space and Rocket Center)

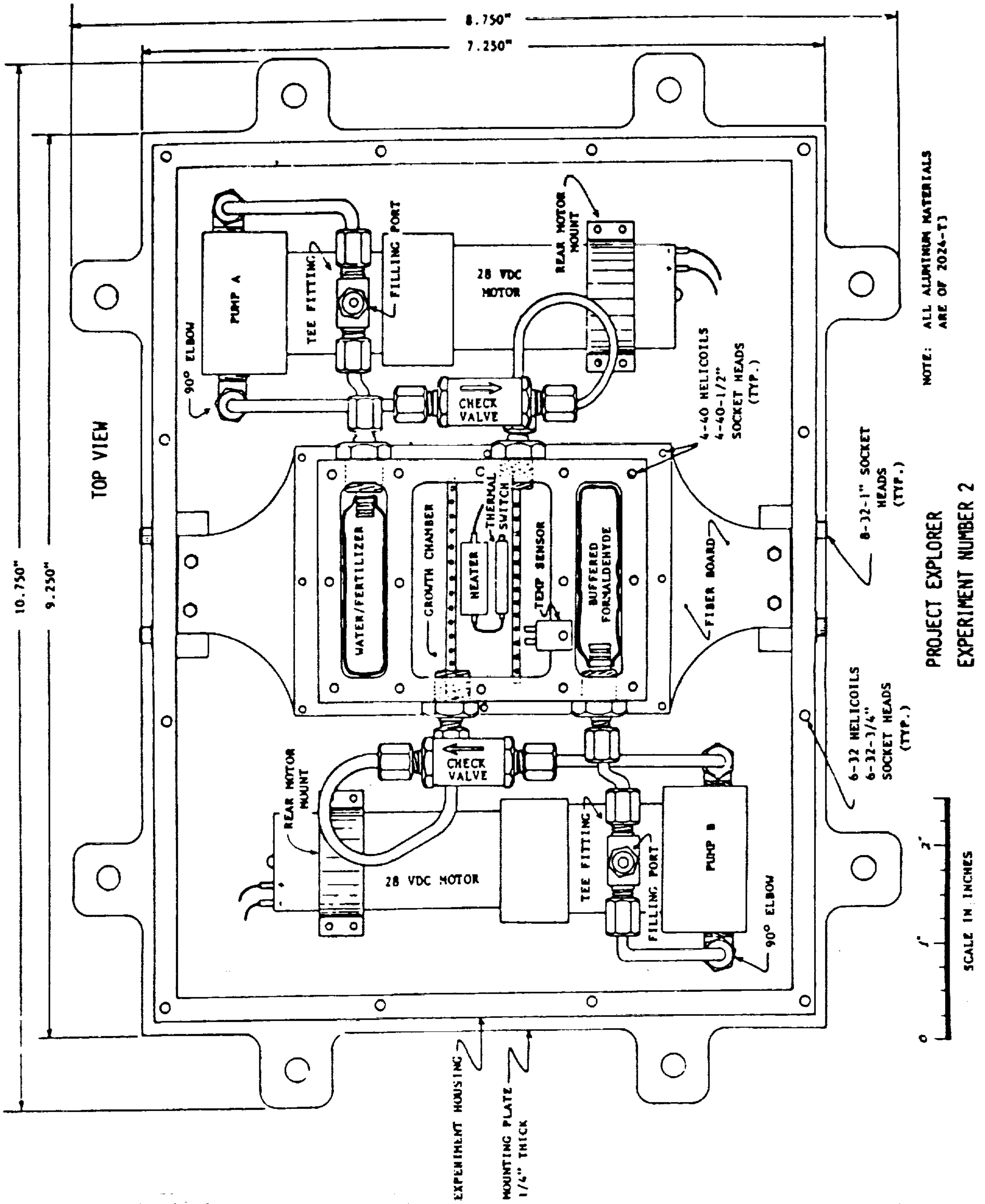

Figure 3. Growth Chamber Diagram for Guy Smith's Radish Seed Experiment from GAS Can #007.[3] The same growth chamber with modifications will be used for this experiment.

[3] Ibid.

MODIFICATIONS

Most of the same materials will be used in GAS Can #608 as were used in GAS Can #007 with the exception of a few materials. Below is a complete list of the changes.

Under # 4 on the Radish Seed Germination Materials Listing, stainless steel tubing has been decided to be used instead of aluminum because of corrosion.

Under # 10, alternate layers of aluminized mylar (or possibly gold coated mylar) and fish net webbing (thickness of a penny) will replace the Ceramic Fiber Insulation.

Under # 12, six heating mats will be used instead of the resistor heater.

Under #17, two neoprene bladders are replacing the two rubber balloons. The neoprene bladders will be coated with activated carbon.

Under #33, ten each of the four seed types mentioned in the Seed Types section will be used instead of the 30 radish seeds used in the previous experiment.

In addition, the corrosion from the existing pumps will be removed so the existing pumps can be reused in this experiment.

PROCEDURE

Time Line for the In-Flight Procedure

- Toggle 1 - Turn computer system on in GAS Can one hour after liftoff.
- At Experimental Elapsed Time (EET) = 0, Turn the Heater On.
- Read Temperature every 1 minute and Record. Read and record continuously throughout the entire experiment.
- If Temperature > 10 degrees Celsius, then turn Pump 1 (water solution) on for 30 seconds.
- At EET=1 hour, turn pump 1 on if not on already for 30 seconds.
- If Temperature < 20 degrees Celsius, then turn heater on.
- If Temperature > 21 degrees Celsius, then turn heater off.
- Toggle 2 - One hour before last allowed time for final toggle.
- Zero seconds after Toggle 2, turn on pump 2 (formaldehyde) for 30 seconds.
- Toggle 3 - Turn off heaters 1 and 2.
- 2 minutes after Toggle 3, turn computer system off in GAS Can.

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