

The Effects of Cosmic and Ultraviolet Rays on Yeast and Seeds

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ABSTRACT

Cosmic and ultraviolet rays are pervasive and often difficult to avoid, for atmospheric pollution has caused an increase in harmful radiation reaching the Earth's surface due to the rapid depletion of the ozone layer. Because the deterioration of the ozone layer is a recent phenomenon, it is important to understand the rays' effects on the DNA of organisms. It is also an area of interest in the field of astrobiology as humans begin to consider the possibility of long-term exposure of crops to these types of radiation in prolonged space travel. The Bioballoon Project, described in this paper, was a payload for a weather balloon built to expose samples of yeast and seeds to cosmic and ultraviolet rays in the middle to upper stratosphere. After plating the yeast and planting the seeds, it was found that although cosmic and UV radiation appeared to induce mutations in the yeast genome, they do not produce significant phenotypic differences in plants.

Background

Cosmic rays are charged, high energy particles, and their direction can easily be changed by the magnetic fields created by bodies throughout space. Because of these common deflections, the rays' sources are often unknown (NASA, 2017). There are different types of electromagnetic rays throughout space, and many permeate the atmosphere and interact with Earth. High energy rays usually do not reach the Earth's surface after colliding with its atmosphere, but particles that result from those collisions often do (Howell, 2018). Earth's atmosphere and magnetic field usually protect organisms from radiation. Thus, a weaker atmosphere or higher altitudes would expose organisms to dangerous levels of cosmic and UV radiation. Certain areas of Earth's atmosphere, such as the ozone layer, have been deteriorated by the release of chlorofluorocarbons by humans, allowing for more cosmic rays to reach the surface and affect organisms (EPA, 2020). To expose the samples to a variety of concentrations, the experiment was placed in a weather balloon payload; as altitude increases, more radiation will reach the payload. Solar radiation is a known human carcinogen, and exposure to high concentrations of ultraviolet radiation is anticipated to be the cause of DNA mutation in skin cells. As the altitude increases, the atmosphere becomes thinner and thus filters less UV radiation (EPA, 2018).

Yeast are simple, single-celled organisms commonly used as model organisms for genetic experiments due to three primary reasons. Firstly, yeast cells are eukaryotic and largely recapitulate the genetic processes of transcription and translation in humans. It is also of note that the yeast genome was sequenced in 1996, making it far easier to conduct genetic studies compared to other organisms. Secondly, many of the same cellular processes and metabolic pathways that occur in human cells occur in yeast cells, such as specific signalling transduction pathways and mitosis (Botstein et al., 1997). This makes yeast highly functional and representative models to make hypotheses about the effects of radiation on human cells based on how it affects the yeast. Finally, yeast are easy and inexpensive to obtain,

with short lifespans and generational times. Therefore, it is easier to produce more strains of yeast from the cells in experimentation, shortening the amount of time necessary for growth and study (Botstein et al., 1997). Specific strains are also nonpathogenic, reducing safety concerns. Thus, yeast can serve as accessible biological models with high fidelity and accuracy.

Like yeast, plants are ideal for this experiment because they are easy to maintain and, depending on the plant species, can reproduce rapidly, allowing for multiple generations of phenotypic data. Particularly relevant to high-altitude experiments is the fact that plant seeds are lightweight and can be easily added to a payload. Although they are still eukaryotes and share some of the same complex biochemical pathways as humans, they possess easy-to-define traits. In addition, plants are much cheaper and ethically sound to use than other organisms.

Past research has explored the impact of cosmic and UV rays on yeast and seeds. Beck-Winchatz et al. demonstrated that yeast colony growth on a high-altitude payload appears to be hindered as compared to a ground control (Beck-Winchatz & Bramble, 2014). However, confounding variables such as cosmic radiation and temperature were not accounted for. Additionally, Tepfer & Leach showed in 2017 that seeds with more protective seed coats such as morning glory had higher UV radiation resistance than thinner-coat seeds such as arabidopsis and tobacco seeds. Thus, our work aims to build upon these findings, testing a wider variety of seed types with varying coat thickness and attempting to control for temperature in yeast experimentation. We hypothesize that plant seeds and yeast cells exposed to UV and cosmic radiation will show more unusual phenotypic features than control groups, indicating change at the genetic level. Our hypothesis will not be supported if UV and cosmic radiation have no effect on the plants and yeast cells.

Procedure

The following materials were used in the payload: a styrofoam container spray-painted orange (1.5 inches wall thickness, inside dimensions 17 x 10 x 8.25 inches), two GoPro Hero 6s, one GoPro Hero 3 (all GoPros with the respective protective cases from GoPro), a battery pack with the corresponding cable for one GoPro Hero 6, Spot Trace GPS, StratoTrack APRS Transmitter, acrylic for windows, hot glue, duct tape, plastic straws, paracord, heavy-duty velcro, and an electric heating pack in addition to the biological samples and sensors. A parachute, a handmade plastic disk for parachute opening, balloon, balloon fill nozzle, and helium were used for the surrounding system.

Spaces for windows were drawn on one short side, the bottom, and the lid. The side and bottom windows were both about 3 x 3 inches and the top window was 10 x 7 inches. The bottom and side windows were on opposite sides of the container and were both in corners, while the top window took about half of the lid, along the shorter edge. The top window was larger so more light could reach the biological samples and the third camera could also record the outside. A lip of about 0.3 - 0.5 inches thick was cut before inserting the windows so the acrylic could rest flush with the outside container walls. Next, the acrylic windows were attached. A half inch to an inch border was scratched around one face of each acrylic sheet using sandpaper. The acrylic sheets were attached using hot glue, and gaps were filled with Elmer's glue. The seams were then secured with weather seal tape. The GoPros were then attached using the mounts they came with. The GoPro Hero 3 was the top-facing camera.

The paracord ran through four holes in the lid, the corresponding holes in the base, and crisscrossed on the bottom to improve stability. There were two paracord strands in the system, one for each diagonal. Inside the payload, as they ran against the corners of the box, the paracord ran through plastic straws to reduce damage to the styrofoam. The straws were hot glued to the payload and extended slightly outside of the payload. A locking carabiner held the payload paracord strands, the balloon line, APRS line, and the parachute line. All lines were attached by climber's knots, though the payload lines were secured with a modified climber's knot that incorporated all four ends. The payload lines were tied on launch day so that the payload was balanced. The paracord parachute line and the APRS line, which were both roughly 15 feet in length, were tied to the parachute loop. The parachute loop was formed from the suspension lines of the parachute, which was sold pre-tied in a loop. The APRS line was only separate because the paracord of the parachute and balloon line were too thick to pass through the APRS tracker. Meanwhile, the balloon

line continued past the parachute loop, through the hole in the plastic disk, through the hole in the middle of the parachute, and all the way to the balloon. This line was knotted once below and once above the plastic disk to secure it in the desired location on the line. The 30 foot balloon line was then tied through a loop made by the folded neck of the balloon just prior to launch.

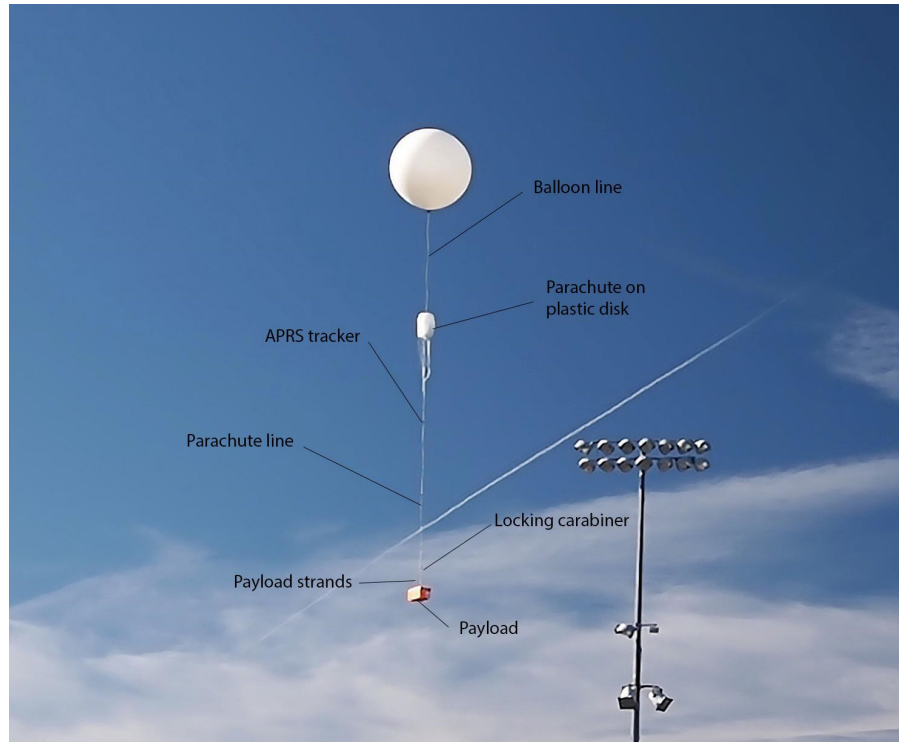


Figure 1: Payload lines with labeled components.

The Spot Trace tracker was placed with the logo facing upwards. It was attached to the base of the styrofoam container with heavy-duty velcro in the corner across from the bottom-facing camera to even out the weight. The handwarmer was secured in the middle of the payload with two sets of velcro straps. The straps were attached to the payload with epoxy, and then each glue spot was overlaid with Gorilla tape. Two pinholes in the payload were poked with a needle, one on each of the shorter faces about a centimeter below the lid opening. This was to reduce the risk of the payload bursting due to air pressure differences.

The following materials were used in the sensors component: Waveshare Temperature sensor, altitude sensor, pressure sensor (BMP388), Waveshare UV Sensor (STM32), an 8 GB Micro SD Card, a bread board (5.2 x 0.5 x 3.3”), an Arduino Uno, jumper wires, 6 polymer lithium-ion batteries, battery connectors, zip ties, outdoor zip tie mounts, and an old plastic container. After coding the sensors, a bread board was used to connect the sensors, SD card, and batteries to the Arduino Uno. Jumper wires connected the sensors, SD card, and batteries within the breadboard. The battery connectors were connected to the batteries in series to provide enough voltage to the Arduino and sensors. The UV sensor’s VCC pin was connected to 3.3V/5.0V in the Arduino, the GND pin was connected to the ground, the SDA pin was connected to SDA/A4, and the SCL pin was connected to SCL/A5. When the sensor components were completely connected, the Arduino was secured to the payload using the holes in each corner of the board. Outdoor, heavy-duty zip tie mounts were attached to the payload in preparation for zip ties to run through the mounts and the Arduino holes. A plastic food container was cut in half and duct-taped to the wall of the payload so it lightly covered all sensors, except the UV sensor, from any possible moving objects in flight. The UV sensor was placed directly under the top window to receive the best light.

Every day for three months before the launch, Jerry Gable's flight predictor (2014) and the Cambridge University Spaceflight Landing Predictor (Sowman et al., 2013) were used to collect landing predictions for the next four days. Wind speed, gusts, landing coordinates, driving time, and noteworthy things about the landing location were recorded. The weather data was from AccuWeather for the launching location.

Preparations were also made for the yeast and plant seed samples. To prepare the yeast, three small plastic trays were each filled with 125 grams of warm, distilled water, two inoculating loops of yeast solution, and 10 grams of YED. The yeast solution was composed of cultured HA1, a, *ade1* strain yeast suspended in 1 mL of pure distilled water. After mixing the contents of each tray, 1 milliliter of each mixture was transferred to three separate microtubes using a small pipette. The tubes were labeled as UV, C, and C+UV to indicate a sample that was to be exposed to ultraviolet radiation, cosmic radiation, or both ultraviolet radiation and cosmic radiation.

Seeds of six common plant species were used to conduct the seed tests: *Brassica rapa*, *Raphanus sativus*, *Lycopersicon esculentum*, *Brassica oleracea*, *Eruca vesicaria*, and *Spinacia oleracea* (Wisconsin fast plant, radish, tomato, kale, arugula, and spinach, respectively). These seed types were selected due to their short germination and maturation times as well as variability in seed coat. For each species, four clear plastic microtubes of 25 seeds were prepared. One tube was labeled with "G" to denote it as a control that would remain on the ground, covered in polyimide film to avoid UV exposure. The other three experimental group tubes were labeled using a similar system as the yeast tubes with UV, C, and C+UV. The UV tubes remained on the ground without special treatment.

On launch day, zippers and velcro on clothing were either covered or not worn to reduce risk of accidental balloon rupture. Inside the school, the hand warmer and Spot Trace were turned on and placed in their respective positions inside the payload. A full charge and strong GPS lock for the Spot Trace were confirmed. The windows were cleaned with water and then covered with Cat Crap, an anti-fogging agent, on both sides. The sensors were confirmed to be receiving data, and then they were zip-tied to the mounts placed before underneath the plastic container. The zip tie tails were trimmed. A battery pack connected to the bottom-facing camera was turned on, as were the cameras. The biological samples (sets of both the yeast and the seeds) were placed inside; a clear Ziploc bag held the ones to be exposed to UV light and was secured to the payload right next to the hand warmer underneath the large top window. Duct tape bubbles attached the bag to the payload. The non-UV samples were wrapped like a burrito in polyimide film, which was taped closed with Scotch tape and sealed similarly except on the wall near the handwarmer. To seal the lid of the payload, weather seal tape was wrapped around the edge of the lid horizontally around the lid perimeter, avoiding the windows. This was repeated with duct tape and then once vertically around the entire payload.

Then, the straw/paracord holes on the lid and base of the payload were sealed with rope caulk. The end of each straw on the top of the payload was sealed to the paracord using 3M silicone weather sealing tape. Fifteen minutes before launch, a nearby air traffic control center was called, as requested by the Federal Aviation Administration (FAA). We had previously submitted the required High Altitude Unmanned Free Balloon Worksheet to the FAA well before launch. The only other governmental requirement was a ham radio technician license to use the StratoTrack, which three members of the team earned.

The payload and supporting systems were brought outside onto the school's football field and set down over a tarp. The StratoTrack was turned on, and sufficient GPS lock and battery voltage level were confirmed.

To inflate the balloon, every person physically involved wore disposable gloves. One person held the payload, and another held the carabiner. The balloon was connected to a helium tank using a safety nozzle, and slowly, helium was let into the balloon as someone held the balloon neck. Four people held the balloon horizontally across their arms until the balloon lifted off them. As they were no longer needed to hold the balloon, those four people went to hold other things, including the parachute and balloon cord. When the balloon was filled with an amount of helium equivalent to eight pounds of lift, the balloon neck was pinched. Two rubber bands were looped to seal the balloon. One was placed at the top neck while the other was placed about three inches from the base of the balloon tail. The tail of the balloon was then folded so that the two rubber bands were touching, and a third rubber band was then tied around the folded neck. Electrical tape was wrapped around the area of the neck with rubber bands. A knot was tied around the neck, which was folded and taped to create a semi-permanent loop, with the cord that passed through the

APRS tracker and went to the carabiner. Any remaining dew was wiped from the windows. Slowly, starting with the people closest to the balloon, every part of the payload and its system were let go except the payload itself. The person holding the cord backed up, moving hand over hand to slowly let the cord up. When the wind was weak, the payload was released. In the first launch attempt, the balloon was underfilled so it had to be reopened and launched again. For the details of the double launch and the errors that caused it, see the discussion section.

Before the payload had reached its maximum height, the retrieval team started driving to the coordinates predicted by the flight predictors, changing the route as necessary after reviewing tracker data. When the payload landed, the Spot tracker reported the coordinates and the now unchanging altitude. The family whose yard it landed in also called the team, using the phone number written on the outside of the payload.

The plating procedure for the yeast had to be done immediately after retrieval to increase the chance of the yeast surviving. This was executed in the back of a car trunk. Clear, sterile, nylon gloves were used to make sure there was no contamination to the specimen. Clorox disinfectant wipes were used to wipe all surfaces. Sealed, sterile plastic loops were used to transfer approximately 2 μL of the yeast solution to pre-prepared agar plates. The sensor data and videos were backed up to computers.

The seeds were planted on May 13, 2020 in various cubic and cylindrical plastic containers. The seeds were sprinkled on top of the dirt and mixed into the soil with a toothpick about a centimeter in. For the cosmic ray only group and some of the ground seeds, every seed was planted, however, for the ground tomato and radish, the C+UV, and UV only groups, only 20 seeds were planted to allow for a uniform sample size and to make counting easier. Every tray was placed on a metal rack in front of a south-facing window and was checked every night around 10 pm for growth. A seed was considered sprouted when its seedling became visible above the soil. Every seed was counted for seven days starting from when the first seeds sprouted. This led to the formation of four groups of seeds that sprouted on the 16th, 17th, 18th, and 19th. Each seed tray was counted two to three times with a toothpick and a crochet stitch counter to ensure an accurate and precise count. The seeds were watered with water and mosquito dunks which contained a bacteria that kills flies. This was done to prevent a fungus gnat infestation. The seeds were watered on May 14th with 700 ml of mosquito dunk water distributed evenly across all plants. On May 21st, the seeds were watered with 1,892.7 ml of mosquito dunk water (8 cups). The experiment ended on May 25th, 2020.

Results

The payload was launched on February 15, 2020 from [school removed for review] High School's football field at 40.375150, -80.052860. Initially, the balloon was underfilled, so the team reopened the balloon to fill it more, successfully launching the second time around 10:10 AM ETC. At the second point from the left in Figure 2, the payload seemed to pause at an altitude of about 22,037 meters (72,300 feet), as measured by the StratoTrack APRS tracker. Then, at the third point from the left, the balloon popped as the payload reached a maximum height of about 33,281 meters (109,190 feet). At about 2:35 PM ETC, the payload landed in Camp Hill, PA at 40.2328, -76.9002. The flight time was estimated to be four hours and twenty-five minutes.

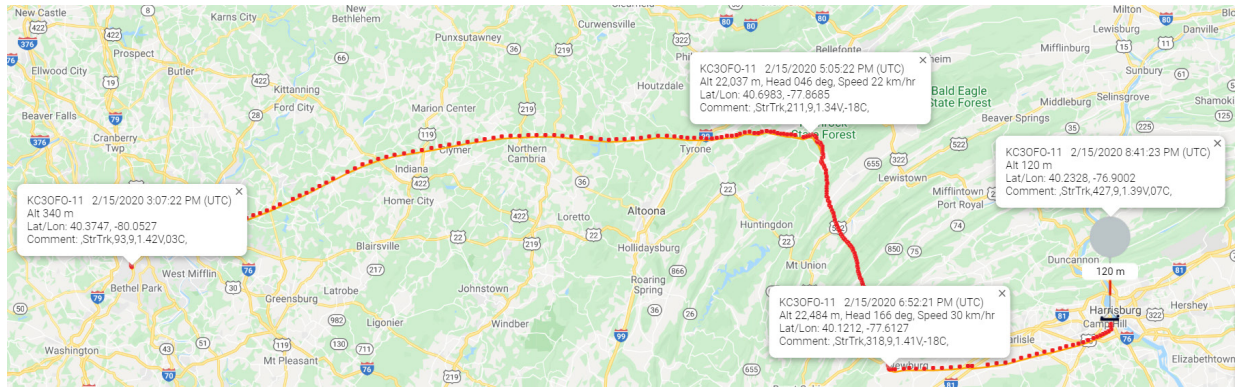


Figure 2: The path of the payload is shown via the StratoTrack APRS tracker. The payload’s starting point is the leftmost, and the landing point is the rightmost. Other notable points are indicated by the corresponding data bubble next to the path.

As seen in Figure 3, the yeast that remained on the ground had red coloration. However, the yeast samples that were sent up in the payload and exposed to the potential mutagens of UV light and cosmic rays had white coloration.

Also, seeds from each of the four conditions were planted, and the percent sprouted are listed in Table 1.

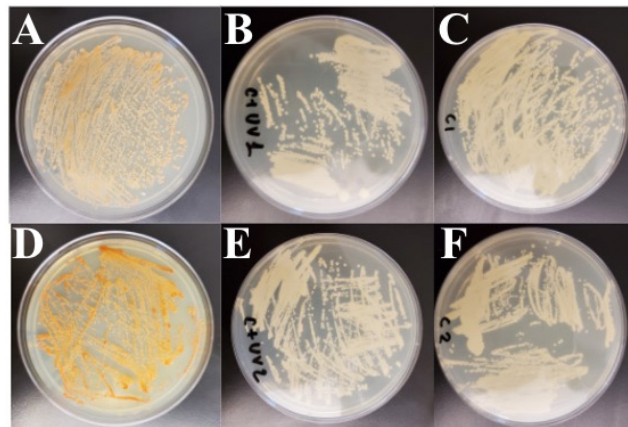


Figure 3: Plated HA1 yeast post-flight. Plates A and B (ground sample controls) were kept on the ground at room temperature encased in polyimide film. Plates C and D are those exposed to both cosmic and UV radiation during balloon flight, and plates E and F are yeast only exposed to cosmic radiation. Clear differences in coloration are visible, with the ground samples showing reddish orange coloration and the flight samples showing a change to a white phenotype.

Table 1: Seeds planted and sprouted.

Treatment	In Vial	Planted	% Sprouted
UV			
Kale	51	20	85
Arugula	116	20	75
Wisconsin	39	20	85
Tomato	41	20	90
Spinach	16	16	63
Radish	40	20	100
UV/Cosmic			
Kale	57	20	90
Arugula	123	20	100
Wisconsin	37	20	90
Tomato	39	20	85
Spinach	16	16	81
Radish	40	20	100
Cosmic			
Kale	68	68	84
Arugula	100	100	100
Wisconsin	38	38	100
Tomato	42	42	83
Spinach	12	12	100
Radish	41	41	95
Ground			
Kale	53	53	87
Arugula	115	115	96
Wisconsin	40	40	83
Tomato	34	20	100
Spinach	16	16	69
Radish	41	20	90

The altitude (Figure 4) steadily increased until leveling off around the maximum altitude, then started to drop around 16,500 seconds. The descent happened more rapidly than the ascent. The pressure (Figure 5) followed the opposite pattern, first decreasing to level off at a pressure in the 900-1,000 pascal range, then increasing as the payload fell back to the ground. The temperature (Figure 6) first increased, then decreased to around 10 C, and then increased and decreased again, finally increasing slightly at the end. Note that the temperature sensor was inside the payload with

the handwarmer, so the recorded temperatures only reflect the environment for the biological samples and not the atmospheric temperature. The higher start temperature is likely due to the sensors being turned on indoors before the payload launched. The first decrease in temperature is likely from the payload's altitude rising through the troposphere. The following increase is likely from when it started traveling through the stratosphere. The following decrease and increase are likely results of the payload falling back down to the earth. For unknown reasons, the UV sensor did not record data after the payload was launched.

In summary, we were interested in how yeast and seeds would be impacted by UV light as well as cosmic rays. Past studies have shown that yeast flown in a similar payload do not grow as much as yeast that stayed on the ground. Researchers have also studied the impact of UV light on some seeds, focusing on the difference in seed coats, though neither the yeast or seed studies discussed cosmic rays or atmospheric conditions. Our aims were to provide support for prior UV conclusions and expand our understanding of how other factors also affect growth.

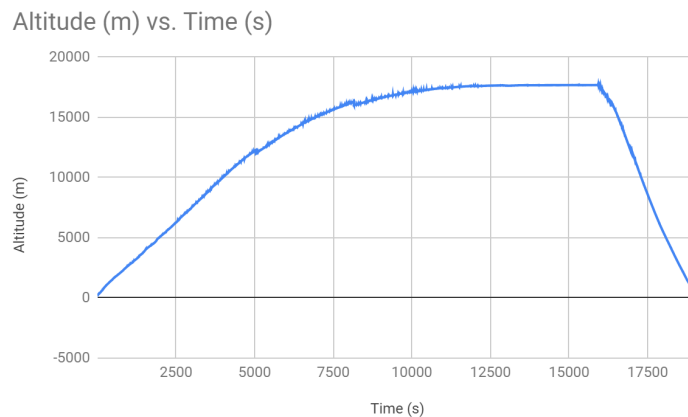


Figure 4: Altitude (m) vs. Time (s).

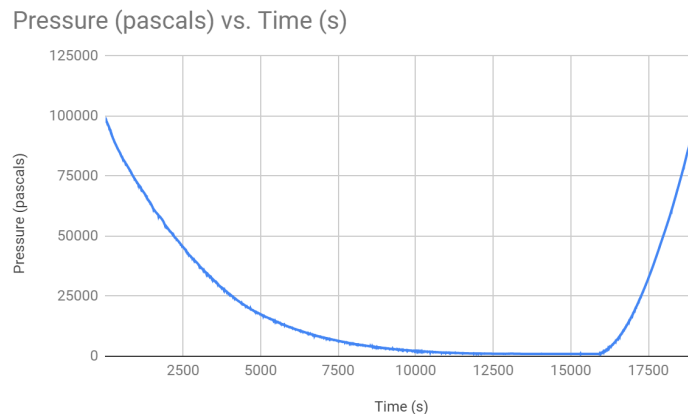


Figure 5: Pressure (pascals) vs. Time (s).

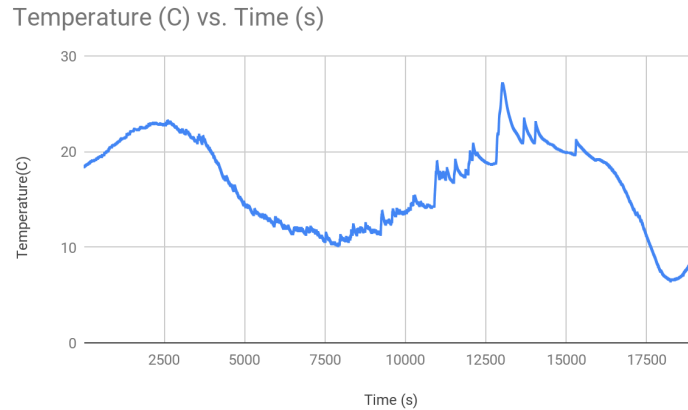


Figure 6: Temperature (C) vs. Time (s).

Analysis

Due to small sample size and limited access to more granular methods such as RNA sequencing and quantitative polymerase chain reaction (qPCR), analysis of yeast results were largely limited to visual observations rather than quantitative methods. Colony sizes appeared to be uniform across plates exposed to cosmic or UV radiation, but they were as a whole larger than the control group. This could be because of the largely uncontrolled and rushed plating conditions in order to preserve yeast viability on the road. Differing colony densities was attributed to differences in streaking methods among group members instead of true differences in colony growth due to UV or cosmic radiation exposure. However, both UV and cosmic ray exposure clearly caused mutations, as the yeast from the payload reverted to a white wild-type phenotype as opposed to the control's red coloration.

For seed data, Fisher's Exact Test of Independence was run on each type of seed to determine if there were significant differences in seeds sprouting after being treated by one of the conditions. Fisher's was used because of the presence of two nominal variables: the type of exposure (UV vs cosmic rays) and the outcome of exposure (sprouting). Additionally, Fisher's is more accurate than a traditional chi-square test with data of smaller sample sizes due to the low expected frequencies of the data (Kim, 2017). In order to more efficiently calculate each test, a website calculator from The College of Saint Benedict and Saint John's University was used (CBSJU, n.d.). However, since the calculator only allowed integer inputs below 100, tests were performed an additional time using an Excel add-on from author and statistician Dr. Charles Zaiontz (n.d.). After comparing results between sources, the Excel add-on had less rounding and had no constraints on input magnitude, so all further Fisher's Exact Test results are reported from the second source in Table 2.

The p-values for kale, tomato, spinach, and radish seeds were all greater than 0.05, indicating that there was no significant difference between the proportion of seeds sprouted in the differing conditions. However, the p-values for arugula and Wisconsin fast plants were both below 0.05, indicating there was a significant difference. Because Fisher's Exact Test considers all conditions for the total result, it was run again for the arugula and Wisconsin fast plant data with the ground condition against each other condition individually in order to determine which condition(s) made the difference. The resulting p-values are reported in Table 3.

Table 2: Fisher's Exact Test of Independence results.

Plant	p-value
Kale	0.95
Arugula	< 0.01
Wisconsin	0.03
Tomato	0.26
Spinach	0.08
Radish	0.52

Table 3: P-values for ground and other conditions.

	Arugula	Wisconsin
UV	0.01	1
UV/Cosmic	1	0.70
Cosmic	0.06	0.01

The only p-values with significant differences below 0.05 were the arugula seeds exposed to only UV light and the Wisconsin fast plant seeds exposed to only cosmic rays. The cause of these results could be due to many different seed factors; it is likely a factor or combination of factors that make arugula seeds different from Wisconsin fast plant seeds, given that the UV light affected only one and the cosmic rays affected only the other. For example, plant seeds possess metabolites called flavonoids and other pigmentation molecules that protect against different wavelengths of photodamage via antioxidant pathways (Agati & Tattini, 2010). The arugula seeds may possess different levels of these antioxidants from Wisconsin seeds, resulting in dissimilar responses to UV and cosmic damage. Differing coat thickness as a function of seed surface area could also affect permeability of seed coats, as demonstrated by Foroughbakhch Pournavab et al. (2019). As for the experiment itself, there may have been sun angle differences through the window, different tube angles, and seeds could have clumped within the test tubes. These factors could result in different amounts of protection of the seeds and/or different concentrations of light that could have led to the significant UV arugula and cosmic Wisconsin results.

Discussion

As mentioned earlier, an error occurred during the filling of the balloon. Although the calculation of the amount of helium needed for a successful liftoff was correct, the original hand scale that was used did not have a large enough scale to show the accurate amount of helium in the balloon. Furthermore, this error was not fully noticed or addressed beforehand, causing the balloon to be underfilled and not rising enough when launched the first time. The balloon and payload were caught before they left the launching field, and more helium had to be added to ensure the correct amount of positive lift. However, the amount of helium in the balloon may have exceeded the needed amount. This process resulted in the balloon experiencing a “double launch.” Later in the flight, the balloon did not pop at the predicted height, which may have been caused by an extra amount of helium, but this cannot be confirmed. Upon the return to the ground, the payload dropped at an extremely rapid pace, which was faster than the predicted descent rate. The most likely reasons the payload descent rate was higher than expected are that the parachute did not fully open or that the parachute was too small for the payload to descend at a slower rate.

Additionally, because of the technological restrictions of working in a typical high school laboratory, much of the biological results were limited to qualitative observations. However, due to the particular strain of yeast used, we were able to make inferences. The HA1 strain contains a mutation in its genome, disrupting the biosynthesis of adenine, an essential nucleobase used to construct DNA. When grown in excess of adenine such as in YEAD media, the HA1 strain obtains adenine from its surroundings and bypasses the biosynthesis pathway, leading to a wild-type phenotype (seen by white colonies). However, in the adenine-deficient YED media, the strain will turn red as it switches to use the adenine biosynthesis pathway through an intermediate metabolite contained within the agar. Essentially, if any mutations occur in the yeast cells that disrupt the biosynthesis pathway, the phenotype reverts back to its wild-type, turning from red to white. This clearly visible change in color makes it possible for researchers to observe the occurrence of certain mutations without the need for more advanced genetic analysis techniques.

The experimental design for the seeds also could have been improved. With greater planting space, more results could have been explored, such as the height, growth rate, and time it took to sprout. Due to COVID-19 and district resource availability, the seeds were planted at home instead of a more suitable lab. Planting more seeds would have been better to have a larger sample size.

The hypothesis that UV light and cosmic rays would cause observable genetic mutations among the yeast and seeds is mostly not supported by the data. The yeast data showed strong evidence that UV and cosmic radiation had an effect on genes involved in the ADE1 pathway as seen by the changes in coloration. However, because only two out of eighteen seed scenarios were significantly different from the ground data, we do not believe this is enough evidence to reject the null hypothesis.

Because it was concluded that UV light and cosmic rays at the altitude reached likely did not result in genetic mutations, it is possible that groups interested in space travel may have greater flexibility. Though more testing would need to be done, these results pose promising suggestions for crops in space. If humans live in space in the future and have sufficient seed planting conditions, their crops would likely still grow if they are receiving a similar amount of UV light and cosmic rays. All of these implications would need to be confirmed with future research.

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