

Gravitational and Space Research

Japanese Oblate Film as a Novel Method for Seed Handling and Activation in Microgravity

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Abstract

In-situ food production for long-duration space missions is currently reliant on crop production, with plants grown from seed serving as a potential source of nutrient supplementation to astronaut diets. Microgravity presents significant challenges to seed handling, growth system integration, and storage. A primary concern is the generation of environmental debris and particulates. This will require extended-duration spaceflight missions to incorporate innovative and reliable methods to handle and prepare seeds for cultivation. This study investigates the potential of Japanese oblate film, a thin, starch-based, edible film traditionally used to wrap ill-tasting powdered medicines, as a method for seed handling in space environments. These films feature a thin, flexible structure that facilitates efficient handling and a water-soluble composition, allowing for integration into cultivation systems. Japanese cherry red radish seeds were adhered to oblate sheets, immobilizing them to prevent debris formation during handling and ensure consistent positioning for growth. The sheets were placed on non-enriched agar media plates, activating the seeds and simulating passive hydroponic systems that could be utilized during future space missions. Results indicate that seeds prepared with oblate film exhibited significantly faster germination rates within the first 24 hours and higher overall germination rates over a seven-day period compared to control groups. This study demonstrates the potential of Japanese oblate film as an effective solution for seed handling and activation in microgravity environments, with possible applications for storage in long duration space agriculture operations.

Keywords

In-situ Food Production • Microgravity Seed Handling • Space Crop Production • Japanese Oblate • Space Agriculture

Introduction

As long-duration space missions extend beyond low Earth orbit to sustained operations on the Moon and eventual exploration of Mars, the feasibility of regular resupply diminishes significantly (Douglas et al., 2020; NASA, 2022). Developing sustainable in-situ food production methods through crop cultivation becomes essential to support crew nutrition and alleviate menu fatigue caused by reliance on repetitive prepackaged meals (Yamashita et al., 2009; Perchonok et al., 2020; Poulet et al., 2022; Douglas et al., 2024).

By enabling astronauts to grow and handle fresh crops, these systems offer much-needed dietary variety and enhance the overall mission experience (Wheeler et al., 2003; Johnson et al., 2021). Seed handling in microgravity presents unique technical and operational difficulties. In microgravity, seeds can become particulate debris, posing risks to both spacecraft systems and crew health. These particulates can interfere with

sensitive equipment such as air filtration and ventilation systems and create potential hazards to humans, including eye injuries or accidental inhalation (Lockhart, 2021). NASA has been actively exploring the application of polymer-based seed films to address similar challenges in space agriculture (Padgett, 2018).

Ground tests using these films have demonstrated faster germination rates compared to on-flight growth experiments, highlighting their potential to enhance crop productivity and adaptability for space applications (Lockhart, 2021; Cawley, 2022). These advancements underscore the capability of film-based technologies to overcome barriers associated with space-based food production.

This growing demand for reliable and efficient seed handling solutions highlights the necessity of integrating novel technologies that can mitigate risks associated with particulate debris and ensure successful crop cultivation in the unique constraints of space environments. The need for innovative approaches to seed

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handling has led to the exploration of Japanese oblate film as a potential solution. Japanese oblate film is a thin, starch-based edible material traditionally used in pharmaceutical applications to encase powdered medicines. Research into edible films, including those made from polysaccharides like potato starch, indicates their biodegradability, environmental friendliness, and safety for consumption. These films serve as effective barriers in food packaging, enhancing both quality and safety (Wang et al., 2024). When exposed to water or moisture, the film rapidly dissolves. This feature was observed to facilitate water transfer to the seeds, initiating their activation. Additionally, the dissolving film helps immobilize the seeds on the surface it contacts, ensuring stability during the initial stages of growth. This water-soluble property allows it to integrate into hydroponic or passive watering systems. These qualities make oblate film particularly attractive for space applications, where minimizing mass, waste, and operational challenges are critical considerations.

The physical and chemical properties of oblate film align well with the challenges of seed handling in microgravity. The immobilization of seeds using oblate film, either through adherence or encapsulation, prevents particulate generation during handling and transfer. This approach also enables astronaut crews to store seeds securely and exercise preferential selection during crop production operations.

Beyond addressing seed handling and activation challenges, oblate film offers additional applications for space agriculture. Current systems, such as the Advanced Plant Habitat (APH) and Veggie hardware aboard the International Space Station (ISS), rely on pre-glued seeds for planting (Massa et al., 2017). While effective, this approach limits the flexibility of on-demand planting and crop selection by crew members. Oblate films provide a modular and adaptable alternative, allowing astronauts to handle and plant seeds dynamically as needed. When producing seed films, seeds may be strategically oriented to optimize growth outcomes, particularly in microgravity environments where orientation plays a critical role under both light and dark conditions. In microgravity, the precise handling of seeds using films allows for controlled orientation, reducing variability and ensuring consistent positioning. Specifically, aligning the seed's micropyle to direct radicle emergence away from the light vector enhances root development and overall growth efficiency (Bekele & Hudnall, 2015; Wojciechowski et al., 2019; Zhang & Lin, 2024). Additionally, this method could serve as an effective storage and transfer system for seeds.

In this study, Japanese cherry red radish seeds were adhered to oblate film and placed on non-enriched agar media to evaluate the potential of this method in addressing the challenges of seed handling and activation. The agar served as an analog to passive hydroponic systems, providing a stable, moisture-retentive surface for seed germination. Agar-based media are widely utilized in both spaceflight and



Figure 1. Examples of successful Japanese cherry red radish microgreen germination at Day After Planting (DAP) 7. (A) Post-experiment specimens grown using the oblate film method, showing successful germination and early development. (B) Close-up of healthy microgreens cultivated using the oblate film method.

ground-based plant biology experiments for tissue cultivation and small-scale plant growth studies, as they provide a reliable and well-established method for supporting plant development under controlled conditions (Meyers et al., 2022; Teng et al., 2022). The findings suggest that Japanese oblate film is a promising tool for improving seed handling, activation, and overall crop production in space (Figure 1). By addressing key challenges posed by microgravity, this method has the potential to significantly enhance the efficiency and sustainability of space agriculture, supporting the nutritional and psychological well-being of astronauts on long-duration missions as humanity advances toward deeper exploration of the solar system.

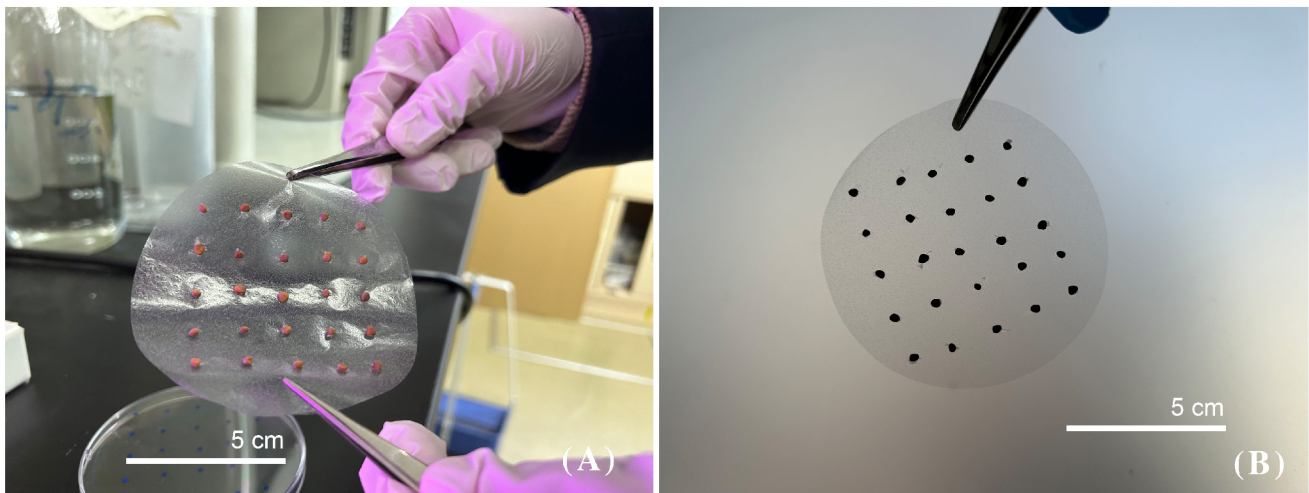


Figure 2. Oblate Film Seed Arrangement. (A) Oblate film arranged with 25 seeds in a uniform grid formation, showcasing its lightweight and flexible properties before placement on agar media. (B) Seeds adhered to the oblate film after placement, demonstrating secure adhesion

Materials and Methods

Commercially available potato starch oblate film sheets (Matsuko Kiyoshi brand; 10% w/w potato starch, 90% w/w water) measuring 9 cm in diameter and 0.01 mm in thickness were used in this study. Japanese cherry red radish seeds (*Akamara Hatsuka* seed type, variety number 01151, Provider: Tohoku Seeds) were selected for adhesion to the films due to previous success in spaceflight (Farid John & Abou-Issa, 2021; NASA, 2020; Hasenstein et al., 2023). Prior to adhesion, all radish seeds were surface-sterilized using a 70% v/v ethanol wash. The seeds were immersed and agitated in 70% v/v ethanol, then thoroughly rinsed with sterile distilled water. Following surface-sterilization, the seeds were allowed to off-gas for 24 hours in a sterile biosafety cabinet to ensure complete evaporation of residual ethanol. Each oblate film was adhered with 25 sterilized Japanese cherry red radish seeds. A small amount of 2% w/v (2M) guar gum solution was added to the seeds to achieve adhesion to the film, with the seeds arranged in a 5x5 grid-like formation (Figure 2). Similar methods using guar gum and films have been employed in space biology research to optimize plant growth and hardware compatibility (Kiss et al., 2007).

The films were allowed to dry for 24 hours before integration. Initial testing consisted of 28 seed film sheets and plates and 28 control group plates. During pre-experiment trials, adhesion was achieved by using clear non-toxic craft glue. This method resulted in successful adhesion, immobilization, activation, and germination as well.

An initial set of 54 non-enriched agar plates were prepared, each plate measuring 90 mm in diameter. The agar media

used in this study, derived from red algae, was prepared as a 2% w/v solution (2 g of agar powder per 100 mL of water) with a molarity of 2 mM, using Yoneyama Extra Pure Reagent 01793 (Product of Yoneyama Medical Industry Supplies, Osaka, Japan; Lot No. TNL 0571). Of these, 28 plates were designated as controls, while the remaining 28 plates were used for the experimental group. The agar served as an analog to passive hydroponic germination systems, providing a stable, nutrient-free medium that maintains consistent hydration for seed activation and initial growth. Its structure enabled water diffusion similar to passive hydration methods applicable in reduced or microgravity environments.

For the control group, 25 sterilized radish seeds were evenly distributed in a grid formation directly on the surface of each agar plate. In the experimental group, each agar plate was covered with an oblate film embedded with 25 sterilized radish seeds in the same formation. The films were carefully placed on the surface of the agar, ensuring full contact between the seeds and the agar medium. (Figure 3) All plates were closed and placed in a controlled cultivation chamber (ADVANTEC, TVG241AA Incubation Chamber). (Figure 4) The chamber was maintained at a temperature between 25-27°C with 60% relative humidity. Plates were illuminated under LED magenta grow lights with a light spectrum composed of 52% red (620 nm), 35% blue (460 nm), and 13% broad-spectrum white LEDs. The lights were positioned at a distance of 60 cm, providing an intensity of approximately 4725 lux and a Photosynthetically Active Radiation (PAR) of approximately $78.66 \mu\text{mol m}^{-2} \text{s}^{-1}$, set to a 16-hour photoperiod per 24 hours. Germination was determined by the visible emergence of radicle or cotyledon structures from the seeds, marking the initiation of plant growth development. Visible germination

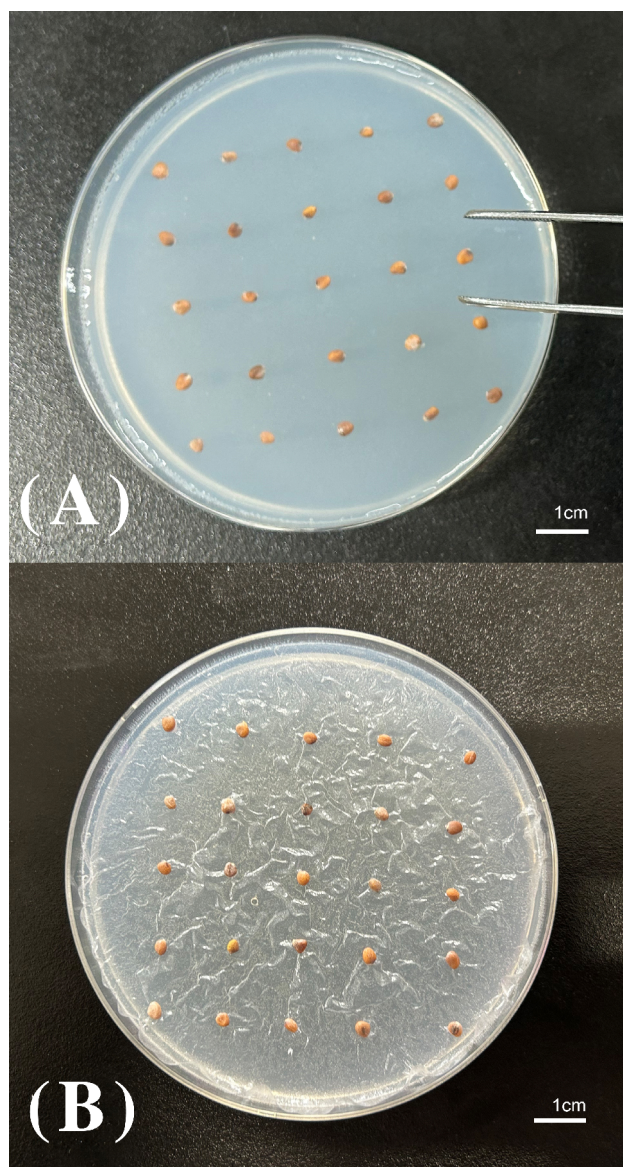


Figure 3. Seed Arrangement and Film Interaction with Agar Media. (A) Seeds arranged in a grid formation directly placed on the surface of the agar media. (B) Oblate film with adhered seeds upon contact with the agar media; the film adheres fully to the agar due to moisture, beginning to dissolve and ensuring the seeds establish direct contact with the moisture for germination.

percentages were recorded 24 hours after planting and then again 7 days after planting (DAP). Following the initial DAP 7 observation period, an additional 9 oblate films were prepared and embedded with sterilized seeds. These films were stored under ambient conditions, average temperature 24°C, 35% RH, for 30 days to test the preservation efficacy of the films. During the storage period, no germination was observed. After 30 days, the stored films were placed on 9 new plates of non-enriched agar. In parallel, 9 additional control plates were

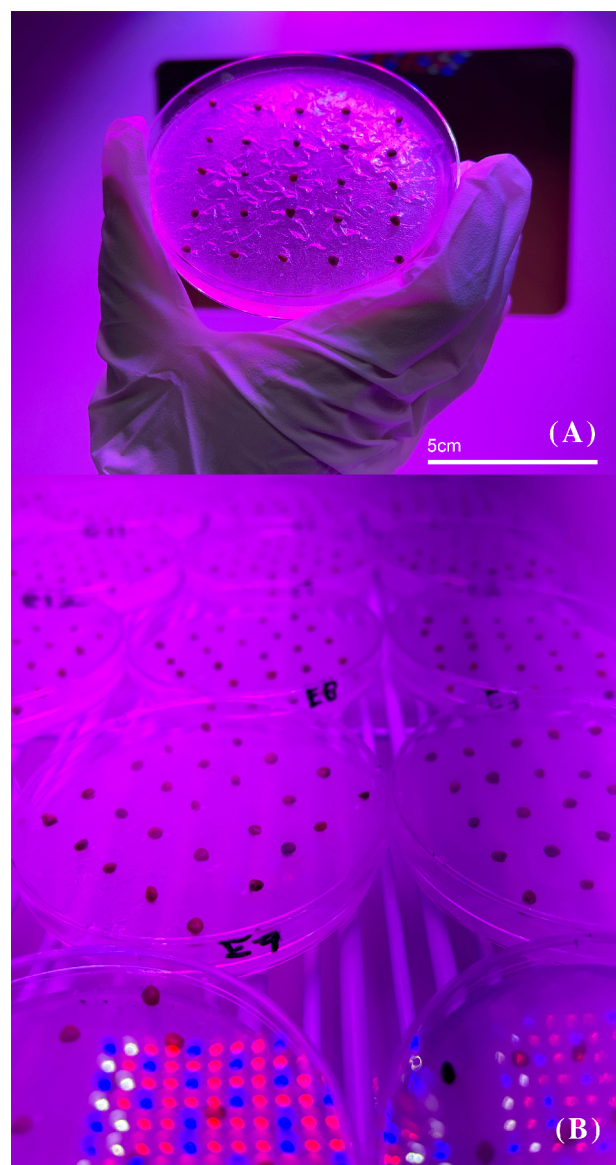


Figure 4. (A) Oblate film with seeds positioned on the agar media, shown prior to sealing the plates and placing them in the growth chamber. (B) View of multiple plates arranged within the growth chamber under controlled environmental conditions for the germination study.

prepared, each with 25 sterilized radish seeds distributed directly on the agar surface. Both groups were then incubated under the same controlled conditions as described above and observed for germination over a 7-day period. A total of 74 plates were prepared and observed, comprising 28 experimental plates with oblate films and 28 control plates in the initial setup, followed by 9 experimental plates with stored films and 9 corresponding control plates. Altogether, 1,850 seeds were planted across the study. Germination rates for

Table 1. Summary of germination percentages and variability for control and experimental (oblate film) groups on Day After Planting (DAP) 1 and DAP 7.

DAP	N	Seed Total	Mean Germination % Control	Mean Germination % Oblate Film	Control St. Dev	Oblate Film St. Dev
DAP 1	37	925	6.5 ± 2.01	68.8 ± 3.20	12.2	19.5
DAP 7	37	925	68.6 ± 2.24	87.3 ± 1.89	13.6	11.5

Descriptive Statistics of Germination Rates for Control and Experimental (Oblate Film) Groups on DAP 1 and DAP 7

Table 2. Results of statistical comparisons for germination rates between control and experimental (oblate film) groups on Day After Planting DAP 1 and DAP 7.

Time Point	Degrees of Freedom (df)	t-Test Statistic (t)	p-value (p)
DAP 1	72	10.78	p < 0.001
DAP 7	72	6.33	p < 0.001

Statistical Analysis of Germination Rates Comparing Control and Experimental (Oblate Film) Groups

both the initial and stored films were analyzed, compared to the control groups, and statistically evaluated using a t-test to assess how the use of oblate films influenced activation and germination rates. All values are reported as mean ± standard error (SE).

Results

Germination Rates on Day 1 (DAP 1)

On the first day after planting (DAP 1), the average germination rate for the control group was 6.5% ± 2.01 (SE), while the experimental group utilizing the potato starch oblate films exhibited a significantly higher average germination rate of 68.6% ± 2.24 (SE) (Table 1; *Figure 5*). The standard deviation for the control group was 12.2%, compared to 19.5% for the experimental group. This suggests greater variability in germination success among seeds adhered to the oblate films.

A t-test was conducted to compare the germination rates between the control and experimental groups on DAP 1. The results indicated a highly significant difference in germination rates, with a t-test statistic (t) of 10.78 and a probability (p) value of 0.00 (df = 72), indicating that the higher germination rate observed in the experimental group was statistically significant (Table 2).

Germination Rates on Day 7 (DAP 7)

On DAP 7, the average germination rate for the control group increased to 68.8% ± 3.20 (SE), while the experimental group showed a further increase to 87.3% ± 1.89 (SE) (Table 1; *Figure 5*). The standard deviation for the control group was 13.6%, while the experimental group had a slightly lower

standard deviation of 11.5%, indicating more consistent germination outcomes with the oblate film method over time.

The t-test comparing germination rates on DAP 7 between the control and experimental groups also revealed a statistically significant difference, with a t-test statistic (t) of 6.33 and a probability (p) value of 0.00 (df = 72), confirming that the experimental group continued to outperform the control group in terms of germination success (Table 2).

Summary of Seed Germination

The experimental group using oblate film demonstrated higher seed activation, leading to significantly improved germination rates (*Figure 6*). This method shows particular promise for use in hydroponic growth systems, such as those that may be utilized in long-duration space missions, where extended seed storage and reliable germination in reduced or microgravity environments will be necessary.

The 9 experimental plates stored for 30 days prior to activation, and the 9 control plates planted on the same day as the experimental plates' integration were included as part of the overall dataset. However, when isolating these 18 plates for analysis, it was observed that the control group exhibited a mean germination rate of 6.2% (SD: 14.86) at DAP 1, which was significantly lower than the experimental group's mean germination rate of 68.9% (SD: 25.28), with a highly significant difference (p < 0.001). By DAP 7, the control group's germination rate increased to 73.3% (SD: 17.59), while the experimental group maintained a higher mean germination rate of 87.1% (SD: 12.04).

The statistical analysis, summarized in Table 2, provides strong evidence that the use of potato starch oblate films significantly enhances the germination rate of seeds compared to the control. Both the DAP 1 and DAP 7 comparisons yielded p-values of p < 0.001, indicating that the observed differences are highly statistically significant and unlikely to be due to random chance.

Discussion

This study highlights the significant potential of films, such as Japanese oblate film, as innovative tools for space agriculture, particularly in addressing the challenges of seed handling

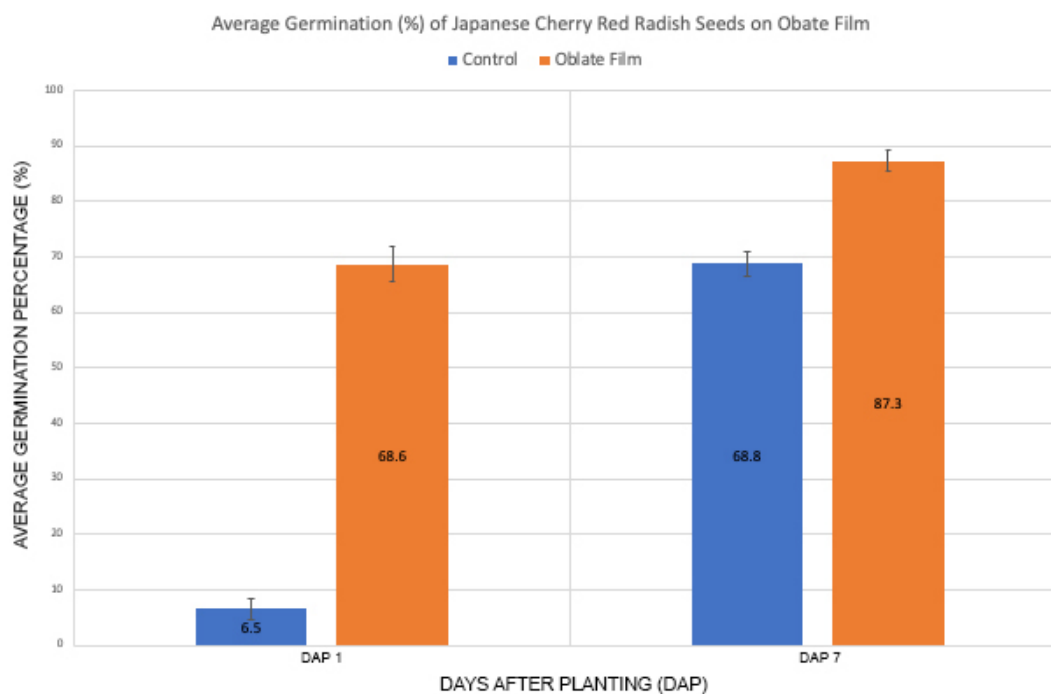


Figure 5. Average Germination Percentage Comparison Between Control and Oblate Film. Bar chart illustrating the average germination percentages for Days After Planting (DAP) 1 and DAP 7. Data compare germination rates between seeds in the control group and seeds adhered to the oblate film. Error bars indicate standard deviation.

and activation in microgravity. The oblate film demonstrated its ability to support both seed immobilization and water-mediated activation, features that are critical for maintaining control over seed placement and germination in the absence of gravity. These properties align with NASA's ongoing research into seed films, which have also shown promise for improving germination rates and offering flexibility in space crop production systems (O'Rourke & Romeyn, 2023; Cawley, 2022; Lockhart, 2021).

The film's versatility extends to biopriming, wherein it can potentially be infused with growth hormones, fertilizers, and beneficial microbes to enhance seed germination and plant productivity. NASA is conducting ongoing studies to evaluate the effectiveness of similar films inoculated with plant growth-promoting microbes, which have shown potential to enhance biomass yields and improve plant resilience under stress conditions (Padgett, 2018; O'Rourke & Romeyn, 2023). Future research should explore the enrichment of oblate films with such agents to further optimize their efficacy in space environments.

While the results of this study are promising, achieving full flight readiness will require additional testing and validation. Establishing standardized metrics, such as a Crop Readiness and Flight Readiness Index, will be essential for evaluating the performance of oblate film under spaceflight conditions, including germination rates, plant growth metrics, and

system integration efficiency. Microbial proliferation testing is also critical to investigate the potential for microbial growth on or within the films and to refine sterilization methods to ensure both astronaut safety and crop viability. Comparisons of various sterilization techniques, such as autoclaving, chemical treatments, and radiation-based methods, will help determine the most effective approach for maintaining seed viability while minimizing contamination risks. Additionally, the variable utility of oblate films, such as encapsulating seeds in seed pockets, can facilitate precise placement, handling, and storage during planting operations, further supporting system integration in space agriculture (*Figure 7*).

In this study, a non-enriched agar was deliberately chosen as the control to mimic passive hydroponic methods without the influence of external nutrients. While the addition of the oblate film significantly improved germination rates compared to the control, it is acknowledged that the starch content in the film may have contributed to this increase by providing a localized energy source for germinating seeds. This is an important distinction from standard agar-based formulas commonly used in spaceflight experiments, which include salts, vitamins, and sugars optimized for growth. Future studies could explore how the germination rates achieved in this study compare directly to those using enriched agar formulas.

Different crops exhibit varying germination behaviors, growth rates, and environmental tolerances, making it essential to

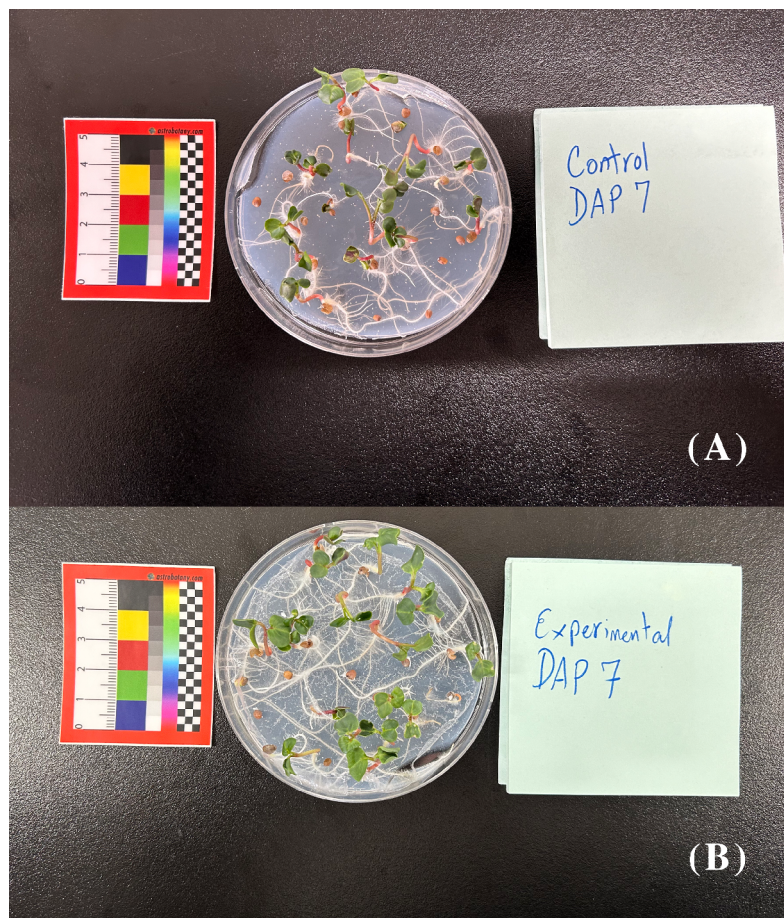


Figure 6. (A) Example of a control plate on Day After Planting (DAP) 7, showing seed germination without the use of oblate film. (B) Example of a plate with oblate film on DAP 7, illustrating germination outcomes with seeds adhered to the dissolvable film.

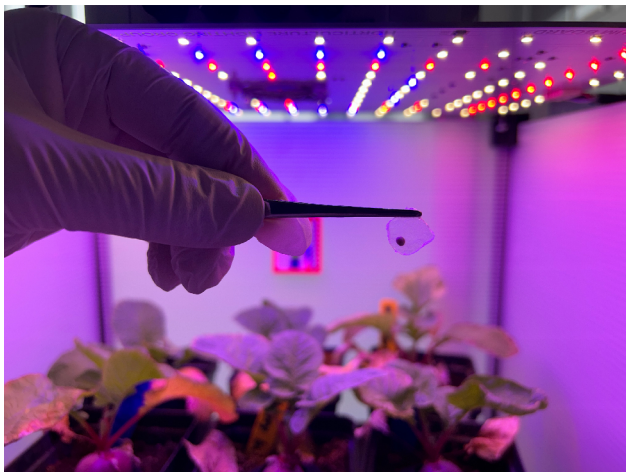


Figure 7. Seed encapsulated within oblate film, forming a seed pocket for optimized handling and germination. In the background, a mature cherry red radish plant grown from these seed pockets during preliminary testing is displayed, demonstrating the effectiveness of the encapsulation method.

expand testing to include a diverse array of species. Future research would greatly benefit from developing a catalog of crops tested with oblate film technology under similar conditions. Such a catalog could provide valuable insights into the adaptability of this method across multiple plant types and its scalability for diverse mission requirements.

Conclusion

Implications for Space Utilization

The successful integration of oblate films into space agriculture systems could revolutionize the way seeds are handled, stored, and activated in microgravity. By reducing particulate generation and offering greater control over seed placement, these films address critical operational challenges. Furthermore, their ability to enhance germination rates and support dynamic crop selection aligns with the broader goal of developing sustainable life support systems for deep space exploration. These advancements not only contribute to the

feasibility of long-duration missions but also open avenues for improving agricultural practices on Earth. This study demonstrates that oblate films are a viable and versatile solution for space-based seed handling and activation, supporting NASA's mission to enable human exploration of the Moon, Mars, and beyond. Future research should focus on refining this technology, ensuring its readiness for deployment, and exploring its integration with existing spaceflight systems.

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Disclosure Statement

No competing financial interests exist.

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