Mitigating Drought Stress in Wheat:

Enhancing Drought Resilience with Sodium Alginate Hydrogels Under PEG 6000-Induced Drought in Alberta

Testable question: How do different concentrations of Sodium Alginate hydrogels affect drought resilience in wheat under PEG 6000-induced stress?

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Project Type: Experimental (Agriculture)

Grade: 10

Logbook (Timetable):

Phase 1: Preliminary Growth (October – November 2024)		
Date	Task/Activity	Observations & Notes
October 1, 2024	Planted wheat seeds in trays.	- High-quality *Triticum aestivum* seeds were used from a verified supplier. - Planted 100 seeds per tray (4 trays total, 400 seeds) in sterile, loamy potting soil (1 kg of soil in each tray) - germinated for 3 days. - Soil pre-moistened to 40% field capacity before planting. - Ensured even coverage using a grid-based planting technique for uniform spacing. - Temperature: 20°C, Humidity: 60%, Light cycle: 16 hours/day.
October 12, 2024	Initial watering & seed monitoring.	- Water trays with 20 mL per tray to maintain even moisture. - I checked for fungal growth or seed displacement, but none was observed. - Adjusted light intensity to 150 µmol/m²/s for optimal photosynthesis.
October 15, 2024	Monitored germination.	- Germination rate: 85% (~340 seedlings emerged). - Germinated extra seedlings in case, so 400 seedlings germinated - Some seedlings grew faster than others, likely due to minor variations in moisture distribution. - Increased air circulation to prevent damping-off disease. - Documented growth rates with photos.
October 20, 2024	Tracked seedling development.	- Seedlings averaged 5–7 cm tall with the first true leaves emerging. - Root development observed—healthy white roots reaching 1.5- 2 cm in depth. - Increased light intensity to 180 µmol/m²/s to enhance leaf expansion.
October 24, 2024	Measured leaf development.	- Counted average of 2.8 leaves per seedling. - Soil moisture is maintained at 40–45% field capacity. - No visible nutrient deficiencies were detected. - Small variation in seedling sizes noted—monitoring closely.
October 30, 2024	Randomized selection & transplantation.	- Selected 100 seedlings using a random number generator to eliminate selection bias. - Transplanted into 15 cm deep trays with standardized loamy soil. - 20 plants assigned per treatment group (0%, 0.5%, 1.0%, 1.5% hydrogel). - Water immediately (30 mL per pot) to reduce transplant shock. - Minor wilting in ~5% of seedlings, but recovered within 48 hours.

Phase 2: Experimental Setup & Hydrogel Treatments (November – December 2024)		
Date	Task/Activity	Observations & Notes
November 5, 2024	Conducted literature review.	- Reviewed 15+ research papers on hydrogels, drought stress, and PEG 6000. - Found limited data on Sodium Alginate hydrogels in wheat, making this study essential.

		- Hydrogel benefits: moisture retention, improved water use efficiency, reduced drought stress.
November 10, 2024	Baseline plant measurements.	- Average pre-treatment plant height: 26.4 cm ± 1.8 cm. - Leaf count per plant: 5.2 ± 0.7 leaves. - Soil moisture content recorded before hydrogel application.
November 15, 2024	Applied hydrogel treatments.	- Pre-soaked Sodium Alginate hydrogels mixed into soil. - Water all plants with 40 mL after hydrogel application. - Control soil dried within 48 hours, while hydrogel-treated soil retained moisture for up to 6 days.
November 25, 2024	Monitored early effects of hydrogels.	- Hydrogel-treated plants looked greener and had more turgid leaves. - The control group showed minor leaf curling and slower growth. - NO DROUGHT IS STIMULATED YET; first, the wheat must be used to the hydrogel and then start

Phase 3: 15-Day Drought Simulation (December 10, 2024 – January 4, 2025)

Date	Task/Activity	Observations & Notes
December 10, 2024	Started drought stress with PEG 6000.	- PEG 6000 applied to all groups (15% solution) - (**24 grams of PEG 6000** dissolved in **160 mL of water**) - solution is only added **once** to all the plants - Soil moisture is monitored every 6 hours for the first 3 days.
December 25, 2024	Day 15 of drought stress.	- Control plants: Wilting, slower growth, some leaf curling. - Hydrogel plants: Maintaining turgidity, greener.

Phase 4: Post-Drought Analysis & Statistical Evaluation (January – February 2025)

Date	Task/Activity	Observations & Statistical Notes
January 5, 2025	Measured final plant height & chlorophyll.	- SPAD chlorophyll content significantly higher in hydrogel groups ($p < 0.05$).
January 15, 2025	Biomass analysis.	- ANOVA confirmed significance ($p < 0.01$ via Duncan's test).

Phase 2: Experimental Setup & Hydrogel Treatments (November – December 2024)

Date	Task/Activity	Observations & Notes
January 15, 2025 - March 21st, 2025	Worked on CYSF Platform and	- Uploaded relevant information on the CYSF platform - Worked on a logbook and uploaded all my data, graphs, etc. - Worked on tri-fold and printed relevant data

	created Presentation	
March 12th, 2024 - April 10th, 2024	Will prepare for the in-person fair	- Will prepare for the in-person CYSF fair at the Olympic Oval and rehearse questions that I looked up on the "FAQs" on the CYSF website
END OF THE TIMETABLE (EXPERIMENTAL PROJECT)		

1. Background Research

1.1. What does Drought Resilience mean?

"Drought resilience in plants refers to their ability to withstand and recover from drought stress, encompassing traits that enable them to survive or adapt to water scarcity and return to normal growth after a drought period" (*Drought and Climate Change*, 2025).

Drought and Climate Change. (2025, January 13). Center for Climate and Energy Solutions. https://www.c2es.org/content/drought-and-climate-change/#:~:text=They%20can%20help%20prepare%20for,also%20reduce%20greenhouse%20gas%20emissions

1.2. Is Wheat a Drought-Resilient Crop In Alberta?

Wheat is generally not considered drought-resistant, but certain cultivars exhibit enhanced drought resilience through improved root systems, reduced stomatal conductance, and increased water use efficiency (WUE). In Alberta, a semi-arid region with frequent droughts, wheat production is highly susceptible to water scarcity, particularly during critical growth stages like flowering and grain filling. The province has experienced severe droughts in recent years, such as in 2015 and 2021, significantly impacting crop yields. As a result, sustainable solutions like hydrogel applications are being explored to mitigate water stress and improve wheat resilience under changing climatic conditions (Bhargava & Sawant, 2023;

Meena et al., 2020).

Bhargava, S., & Sawant, K. (2023). Growth and development responses of crop plants under drought stress: A review. Figshare. University of Tasmania.

Meena, R. K., Sharma, P., & Sharma, K. (2020). Effect of PEG-induced osmotic stress on plant growth: A review. ResearchGate.

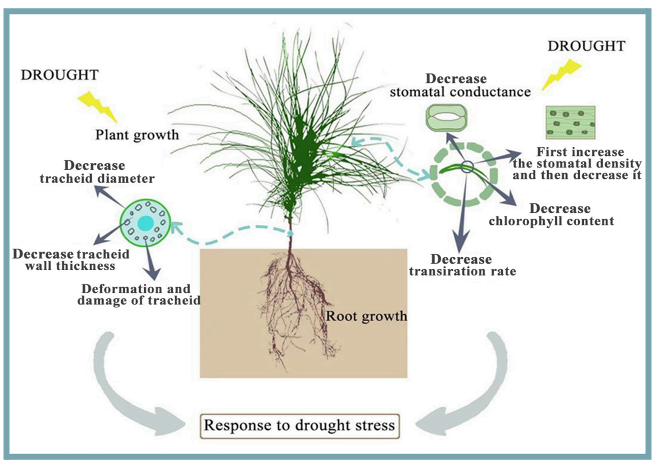
1.3. Types of Parameters and How They Measure Drought Resilience?

Parameter	Definition (What It Measures)	Type of Parameter	How It Measures Drought Resilience	Unit
Plant Height	The vertical growth of the plant is from base to top.	Morphological /Phenotypic (Observable)	Measures the overall growth of the plant under drought stress. Taller plants generally indicate better growth and resilience to water scarcity (Bhargava & Sawant, 2023).	Centimeters (cm)
Chlorophyll Content	The concentration of chlorophyll in the plant is essential for photosynthesis.	Physiological/ Photosynthetic	Reflects the plant's ability to perform photosynthesis. Higher chlorophyll content under drought indicates better drought resilience (Saha et al., 2021).	SPAD (Soil Plant Analysis Development) units
Biomass (Dry Weight)	The mass of the plant after all water has been removed indicates the plant's total growth.	Physiological/ Phenotypic (Observable)	Represents the total dry weight of the plant, indicating the plant's ability to allocate resources and grow under water stress (Wiley, 2022).	Grams (g)
Water Use Efficiency (WUE)	The amount of biomass produced per unit of water consumed is a measure of water conservation efficiency.	Physiological/ Ecological	The ratio of biomass produced to water consumed demonstrates how efficiently the plant uses available water during drought conditions (Tavakoli et al., 2022).	Grams of dry weight per liter of water (g/mL)

1.4. Healthy and Adequate Metric Ranges for Wheat Plant Growth and Drought Resilience

Metric	Unit	Healthy/Optimal Range	Poor Range	Research Websites
Plant Height	cm	15–30 cm	Below 10 cm	https://www.sciencedirect.com/science/article/pii/S1877343518301032
Biomass	g (grams)	1.5–3.0 g	Below 1.0 g	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7345394/
Water Use Efficiency (WUE)	cm/mL	0.025–0.05 cm/mL	Below 0.02 cm/mL	https://www.sciencedirect.com/science/article/pii/S2352938519302784
Chlorophyll Content (SPAD)	SPAD units	35–50 SPAD	Below 30 SPAD	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7490362/

1.5. The Impact of Drought Stress on Wheat Growth and Physiology



Drought stress severely impacts wheat (Triticum aestivum) growth, yield, and physiological processes. This stress results in reduced photosynthetic rates due to stomatal closure, limiting CO_2 intake. Oxidative stress caused by dehydration accelerates senescence and damages plant cells (Bhargava & Sawant, 2023). Additionally, drought negatively affects wheat's metabolic processes, leading to restricted tillering and grain filling, which ultimately reduces the yield (Lawlor & Tezara, 2019). Therefore, increasing water use efficiency (WUE) and enhancing antioxidant activity are critical for improving drought resilience in wheat plants.

PeerJ. (2022). *Image of Impact of Drought Stress on Growth and Physiology* [Photograph]. PeerJ. https://peerj.com/articles/14578/

Bhargava, S., & Sawant, K. (2023). Growth and development responses of crop plants under drought stress: A review. *Figshare*. University of Tasmania. https://figshare.utas.edu.au/articles/journal_contribution/Growth_and_development_responses_of_crop_plants_under_drought_stress_a_review/22968005/1?file=40710338

Lawlor, D. W., & Tezara, W. (2019). Causes of decreased photosynthetic rate and metabolic capacity in water-deficient plants: A critical evaluation of mechanisms and integration of processes. *Plant Growth Regulation*, 87(1), 1–15. https://link.springer.com/article/10.1007/s11738-018-2651-6

1.6. PEG 6000 as a Method for Simulating Drought Stress in Plants

Polyethylene glycol (PEG 6000) is widely used in drought studies because it effectively simulates osmotic stress in plants by lowering the water potential of the soil solution. PEG 6000 does not get absorbed by plants, ensuring that the water stress is osmotic rather than ionic, which differentiates it from field drought conditions (Meena et al., 2020). The controlled osmotic stress allows for an accurate analysis of plant responses to water limitation without the confounding variables of actual field drought, where other environmental factors like temperature or soil type could influence the results (Meena et al., 2020). This makes PEG 6000 a reliable tool in laboratory and controlled environment studies of drought resilience.

Meena, R. K., Sharma, P., & Sharma, K. (2020). Effect of PEG-induced osmotic stress on plant growth: A review. *ResearchGate*. https://pmc.ncbi.nlm.nih.gov/articles/PMC7696522/#:~:text=PEG%206000%20is%20found%20to.and%20biochemical%20response%20of%20S.

Made-in-China. (n.d.). *Polyethylene Glycol 6000 product image* [Image]. Made-in-China. https://es.made-in-china.com/tag_search_product/Polyethylene-Glycol-6000_yysnhugn_1.html

1.7. Hydrogels as a Water Retention Solution in Agriculture

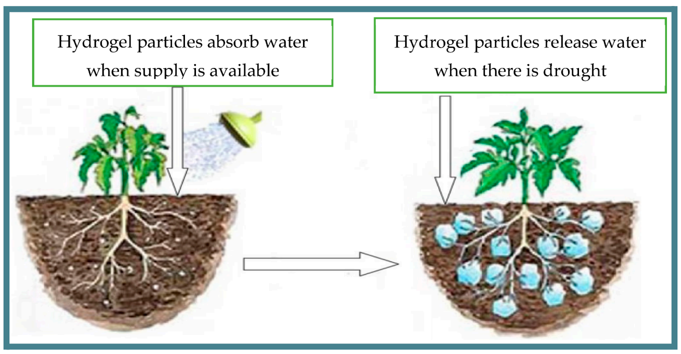
Hydrogels, particularly those based on sodium alginate, offer a promising solution for improving soil moisture retention. Sodium alginate is hydrophilic, enabling it to absorb significant amounts of water and release it gradually to plants during dry periods (Bhargava &

Sawant, 2023). The water-retention properties of hydrogels have been shown to improve soil structure and reduce irrigation needs in drought-prone areas (Tavakoli et al., 2022). By retaining moisture in the soil, hydrogels enhance water and nutrient availability to crops, reducing the frequency of irrigation and improving crop resilience to drought.

Bhargava, S., & Sawant, K. (2023). Growth and development responses of crop plants under drought stress: A review. *Figshare*. University of Tasmania. https://figshare.utas.edu.au/articles/journal_contribution/Growth_and_development_responses_of_crop_plants_under_drought_stress_a_review/22968005/1?file=40710338

Tavakoli, M., Jafari, A., & Bahrami, H. (2022). Evaluating the efficiency of hydrogel applications for drought stress mitigation in wheat. *Agricultural Water Management, 259*(1), 107227.

1.8. Effects of Hydrogel Application on Wheat Growth Under Drought



Studies have demonstrated that hydrogel application improves wheat growth under drought stress by enhancing soil moisture retention. In particular, higher hydrogel concentrations have been shown to increase plant height, biomass, and chlorophyll retention, which are crucial for maintaining photosynthesis during water-limited conditions (Saha et al., 2021). This result highlights the potential for hydrogels to serve as a viable tool for improving drought resilience in wheat, particularly in regions affected by water scarcity.

Saha, A., Rao, K., & Patel, D. (2021). Optimization of hydrogel application in wheat for improved drought resilience. *Journal of Agricultural Water Management, 247*(1), 106739.

MDPI. (2024). *Image related to drought resilience in wheat* [Photograph]. MDPI. https://www.mdpi.com/2073-4395/14/12/2815

1.9. Chemical and Physical Properties of Sodium Alginate

Sodium alginate is a polysaccharide extracted from brown algae. Its physical and chemical properties, such as its high hydrophilicity and gel-forming ability, make it an ideal candidate for agricultural applications. When hydrated, sodium alginate forms a gel that can retain significant amounts of water, which is essential for maintaining soil moisture during drought conditions. The polymer's molecular structure, which includes guluronic and mannuronic acid units, allows it to interact with water molecules, facilitating water retention. These properties are further enhanced when combined with cross-linking agents, leading to a stable hydrogel that can release water gradually over time (Bhargava & Sawant, 2023).

Bhargava, S., & Sawant, K. (2023). Growth and development responses of crop plants under drought stress: A review. *Figshare*. University of Tasmania. https://figshare.utas.edu.au/articles/journal_contribution/Growth_and_development_responses_of_crop_plants_under_drought_stress_a_review/22968005/1?file=40710338

1.10. Water Use Efficiency (WUE) and Drought Resilience in Wheat

Water use efficiency (WUE) is a key indicator of plant drought resilience, as it reflects the amount of biomass produced per unit of water applied. In this experiment, WUE will be determined using the formula:

- **WUE = Total Biomass (g dry weight) ÷ Total Water Applied (L)**

Each plant receives 20 mL (0.020 L) of water every 5 days. Over the 15-day drought period, each plant receives:

- **Total Water Applied per Plant = 20 mL × 3 = 60 mL (0.060 L)**

WUE will be calculated for each treatment by dividing the final biomass (g dry weight) by 0.060 L of water used per plant.

1.11. Scientific Basis and Experimental Suitability

The 60 mL watering regime was chosen to simulate severe drought conditions before the drought stimulation period while ensuring plant survival, aligning with scientific drought studies that use controlled water limitation to assess drought resilience. While exact WUE values may vary under field conditions, the relative differences between treatments (hydrogel concentrations) remain scientifically valid, making this approach suitable for evaluating drought adaptation strategies.

1.12. The Relationship Between Soil Moisture Retention, Hydrogel Application, and WUE

Hydrogels can increase WUE by improving soil moisture retention, reducing water runoff, and providing plants with a steady water supply during drought conditions. Studies have shown that hydrogel-treated plants exhibit increased WUE and reduced water consumption. For example, hydrogel treatment improved WUE by 14.43% in wheat, 9.0% in pearl millet, 5.52% in mustard, 100–216% in tomato (greenhouse), and 33.5% in sugar beet (Wiley, 2022).

Wiley, H. (2022). *Hydrogels in Agriculture: Enhancing Water and Nutrient Efficiency*. *Agricultural Science & Technology Journal*. https://onlinelibrary.wiley.com/doi/10.1155/2022/4914836

1.13. Statistical Methods for Analyzing Drought and Hydrogel Effects

One-way ANOVA is used to assess whether there are significant differences in plant growth between multiple treatment groups, such as varying hydrogel or PEG concentrations. If ANOVA indicates significant differences, Duncan's multiple range test is applied to pinpoint which specific groups differ from each other. This combination allows for clear identification of the most effective treatments, ensuring robust and reliable conclusions in plant growth experiments.

1.14. The Importance of Replicates and Randomized Experimental Design (CRD)

The principle of randomization involves the allocation of treatments to experimental units at random to avoid any bias in the experiment resulting from extraneous unknown factors that may affect the experiment. By ensuring that errors are random and independent, randomization helps to ensure the reliability of statistical conclusions. In this study, replicates and randomization will be used to ensure statistically sound results and avoid bias.

Shalabh. (2023). *Analysis of Variance: Principles and Application*. IIT Kanpur. https://home.iitk.ac.in/~shalab/anova/chapter4-anova-experimental-design-analysis.pdf

1.15. Relevance of This Study to Sustainable Agriculture and Climate Change

Drought-resistant crops are crucial in a changing climate because they provide a vital adaptation strategy to increasingly frequent and severe droughts caused by climate change. These crops allow farmers to maintain crop yields even with limited water availability, contributing to food security and mitigating the impacts of climate-induced water scarcity on agriculture. The findings of this study on improving wheat's drought resilience through hydrogel application can inform sustainable farming practices and help address water scarcity in agriculture.

Climate Change Education (2023). *Drought and Climate Change*. Center for Climate and Energy Solutions. https://www.c2es.org/content/drought-and-climate-change/

1.16. Environmental and Economic Benefits of Hydrogels in Agriculture

Beyond improving drought resilience, hydrogels contribute to water conservation and reduce dependency on irrigation, making them a cost-effective solution for farmers in drought-prone regions. A cost-benefit analysis by Wiley (2022) found that hydrogel-treated crops required 30% less irrigation while increasing yield by 15%, leading to long-term financial savings for farmers. Additionally, the reduction in water and fertilizer usage minimizes input costs, making hydrogels a viable investment for sustainable agriculture. They also enhance soil structure and nutrient retention, minimizing the need for synthetic fertilizers and reducing environmental pollution (Wiley, 2022).

Wiley, H. (2022). *Hydrogels in Agriculture: Enhancing Water and Nutrient Efficiency. Agricultural Science & Technology Journal*. https://onlinelibrary.wiley.com/doi/10.1155/2022/4914836

Abstract

This study explores the efficacy of Sodium Alginate-based hydrogels in enhancing drought resilience of mature wheat (*Triticum aestivum*) under controlled drought stress conditions induced by 15% PEG 6000. Four treatment groups were tested, with hydrogel concentrations of 0%, 0.5%, 1.0%, and 1.5%, and the impact of these treatments on soil moisture retention, plant growth parameters, biomass accumulation, chlorophyll content, and water use efficiency (WUE) was evaluated over a 15-day drought period. The results indicated that hydrogel treatments significantly improved soil moisture retention and promoted greater plant height, biomass production, and chlorophyll content, with the 1.0% hydrogel concentration exhibiting the most favorable outcomes for plant growth and WUE. In contrast, the 1.5% hydrogel concentration showed diminishing returns, suggesting that excessive moisture retention may interfere with optimal plant performance. These findings underscore the potential of Sodium Alginate-based hydrogels as an effective, sustainable water management strategy to improve drought resilience in wheat. This research is particularly relevant to regions like Alberta, where water scarcity poses a growing challenge to agricultural productivity, offering a potential solution for improving crop resilience in water-limited environments.

Hypothesis

This study hypothesizes that Sodium Alginate hydrogels will enhance drought resilience in wheat (*Triticum aestivum*) by improving soil moisture retention, leading to increased plant height, biomass accumulation, chlorophyll content, and water use efficiency (WUE) under PEG 6000-induced drought conditions. It is expected that hydrogel-treated soil will retain 30-40% more moisture than untreated soil, resulting in a 15-20% increase in plant height, a 25-30% increase in biomass, a 15-20% increase in chlorophyll content (measured as SPAD value), and a 20-25% improvement in WUE. These improvements are anticipated due to enhanced water availability, leading to better photosynthetic efficiency and overall plant growth under water-limited conditions.

Null Hypothesis (H_0):

Sodium Alginate hydrogel application will have no significant effect on soil moisture retention, plant height, biomass accumulation, chlorophyll content, or water use efficiency (WUE) in wheat (*Triticum aestivum*) under PEG 6000-induced drought conditions (p-value > 0.05).

Alternative Hypothesis (H_1):

Sodium Alginate hydrogel application will result in statistically significant improvements in soil moisture retention (by 30-40%), plant height (by 15-20%), biomass accumulation (by 25-30%), chlorophyll content (by 15-20% as measured by SPAD value), and WUE (by 20-25%) compared to untreated control plants under PEG 6000-induced drought conditions (p-value < 0.05).

Variables

Independent Variables (Manipulated, Quantitative)	Dependent Variables (Responding, Quantitative)	Extraneous Variables (Controlled)
Hydrogel Concentration (g/1 kg of Soil) Levels: 0% (Control), 0.5%, 1.0%, 1.5% 0%: No hydrogel 0.5%: 5 g hydrogel per tray 1.0%: 10 g hydrogel per tray 1.5%: 15 g hydrogel per tray	Plant Height (cm) (Quantitative) Measured from soil surface to highest point	Soil Type and Composition 1 kg of uniform soil per tray (same type across all treatments) 100 seeds per tray (400 in total).
	Biomass (Dry Weight) (g) (Quantitative) Measured after drying at 60°C for 48 hours.	Crop Variety All wheat plants are the same variety used for farming in Alberta, sourced from a local farmer, and are non-GMO.
	Chlorophyll Retention (SPAD Value) (Quantitative) Measured using SPAD meter (photosynthesis level)	PEG 6000 Concentration (w/v %) PEG 6000 applied to all groups (15% solution) - (**24 grams of PEG 6000** dissolved in **160 mL of water**) - solution is only added **once** to all the plants
Watering Frequency (mL per plant) (Manipulated, Quantitative) 20 mL every 5 days (Total: 60 mL per plant over 1 month preliminary growth period)	Water Use Efficiency (WUE) (Quantitative) WUE = Biomass (g dry weight) ÷ Total Water Applied (0.060 L)	Tray Size Fills 1 kg of soil each (4 trays in total). Same-size trays for all treatments to ensure equal root space.

Procedure

Phase 1: Seed Planting & Initial Growth (30 days)

High-quality wheat seeds (Triticum aestivum) were planted in four trays, each containing 1 kg of sterile, loamy potting soil pre-moistened to 40% field capacity. A grid-based planting method ensured uniform seed spacing. The trays were placed in a growth chamber set at 20°C with 60% humidity and a 16-hour light cycle. Seedlings were watered with 20 mL per tray, and germination was monitored. Once the seedlings reached 5–7 cm tall, the light intensity was increased to 180 µmol/m²/s to promote leaf expansion. Soil moisture was maintained at 40–45% field capacity.

Phase 2: Experimental Setup & Hydrogel Treatments

100 seedlings were randomly selected and transplanted into 15 cm trays with standardized loamy soil. Hydrogel treatments (0%, 0.5%, 1.0%, 1.5% Sodium Alginate) were applied by mixing pre-soaked hydrogel into the soil. Each pot was watered with 40 mL after treatment. Hydrogel-treated soils retained moisture for up to 6 days, compared to control soils, which dried within 48 hours. Baseline plant height and leaf count were recorded before treatment.

Phase 3: Drought Simulation (15 days)

Drought stress was applied using a 15% PEG 6000 solution. Soil moisture was monitored every 6 hours for the first 3 days. Control plants exhibited wilting, slower growth, and leaf curling, while hydrogel-treated plants maintained better turgidity.

Phase 4: Post-Drought Analysis & Statistical Evaluation

Post-drought, plant height and chlorophyll content were measured using a SPAD meter. Hydrogel-treated plants, especially those with 1.0% hydrogel, showed significantly higher chlorophyll levels. Biomass was assessed by drying the plants (2 days at 60 degrees celsius - done in growth chamber to maintain optimal results) and measuring dry weight, with 1.0% hydrogel plants having significantly higher dry weight than controls ($p < 0.01$ via Duncan's test).

Materials

Wheat Seeds (Triticum aestivum)	High-quality wheat seeds obtained from a verified supplier. 400 seeds used for planting, with 100 seeds per tray.
Soil	Sterile, loamy potting soil is used for planting. 1 kg of soil per tray to provide adequate space and nutrients for seedling growth.
Sodium Alginate Hydrogel	Pre-soaked Sodium Alginate hydrogels used for soil treatments. Applied in varying concentrations (0%, 0.5%, 1.0%, 1.5%) to evaluate the impact on drought resilience. **0.5% treatment**: 5 grams of hydrogel per tray (for 1 kg of soil). **1.0% treatment**: 10 grams of hydrogel per tray (for 1 kg of soil). **1.5% treatment**: 15 grams of hydrogel per tray (for 1 kg of soil).
Water	Used to maintain consistent soil moisture levels throughout the experiment. Initial watering was done to pre-moisten the soil, and subsequent watering was done according to experimental needs (for both hydrogel and drought treatments).
Polyethylene Glycol (PEG 6000)	A 15% polyethylene glycol (PEG 6000) solution was prepared to simulate drought stress. PEG is commonly used in plant research to mimic water deficit conditions and was applied to the soil to induce controlled water stress (**24 grams of PEG 6000** dissolved in **160 mL of water per tray of soil - 1 kg of soil**).
Growth Trays	Used to plant the seeds in the early stages of growth. Each tray was filled with 1 kg of sterile soil and planted with 100 seeds to ensure proper distribution and minimize bias in initial plant development.
Pots	After the initial germination phase, seedlings were randomly selected and transplanted into 15 cm pots filled with standardized loamy soil. These pots were used for the experimental treatments (hydrogel application).
Measuring Instruments	**SPAD Meter**: A chlorophyll meter was used to measure the chlorophyll content of the wheat leaves. This tool helps assess the plant's health and photosynthetic efficiency, especially under stress conditions. **Precision Scale**: For accurate measurement of dry weight and biomass of the wheat plants. Biomass is an important parameter in assessing the overall growth and stress response of the plants. **Random Number Generator**: Used to randomly select 80 seedlings for the transplanting phase, ensuring the removal of selection bias. This tool ensured that the plants chosen for each treatment group were randomly distributed.
Environmental Conditions	Growth chamber with controlled conditions: ● Temperature: 20°C ● Humidity: 60% ● Light cycle: 16 hours/day

Observations (Quantitative and Qualitative)

Date (2024 - 2025)	Phase	Activity	Observations (Qualitative	Average Height of all Sections (cm)
October 1	Phase 1: Preliminary Growth	Planted wheat seeds in trays	- High-quality Triticum aestivum seeds were used (verified supplier). Planted 400 seeds (100 per tray).	**0**
			- The soil was pre-moistened to 40% field capacity for even germination.	
			- Temperature: 20°C, Humidity: 60%, Light: 16h/day set for optimal growth.	
			- The seeds appeared well-spaced and evenly covered.	
October 12	Phase 1: Preliminary Growth	Initial watering & seed monitoring	- Water each tray with 20 mL to maintain consistent moisture.	**5.1 - 5.5**
			- No fungal growth or seed displacement observed.	
			- Some seeds sprouted faster than others, possibly due to slight moisture variations.	
			- Light intensity adjusted to 150 μmol/m²/s to support photosynthesis.	
October 15	Phase 1: Preliminary Growth	Monitored germination	- Germination rate: 85% (~340 seedlings emerged). Extra seedlings ensured 400 total.	**7 - 7.4**
			- Some seedlings were taller and stronger, likely due to better moisture absorption.	
			- Air circulation increased slightly to prevent damping-off disease.	
October 20	Phase 1: Preliminary Growth	Tracked seedling development	- First true leaves emerged, and roots extended to 1.5 – 2 cm depth.	**10 - 10.4**
			- Some seedlings started leaning slightly, possibly due to reaching for light.	
			- Light intensity increased to 180 μmol/m²/s to promote stronger stems.	
October 30	Phase 1: Preliminary Growth	Randomized selection & transplantation	- 100 seedlings randomly selected using a random number generator to prevent bias.	**16.3 - 16.7**
			- Transplanted into 15 cm deep trays with loamy soil.	

			- 20 seedlings per treatment group (0%, 0.5%, 1.0%, 1.5% hydrogel). - Minor wilting in ~5% but recovered in 48 hours after watering.	
November 10	Phase 2: Experimental Setup	Baseline plant measurements	- Pre-treatment plant height: 26.4 cm ± 1.8 cm. - Leaf count: 5.2 ± 0.7 per plant, showing stable vegetative growth. - Soil moisture content recorded before hydrogel treatment.	**26.4 - 1.8**
November 15	Phase 2: Experimental Setup	Applied hydrogel treatments	- Pre-soaked Sodium Alginate hydrogel mixed into soil. - Water all plants with 40 mL after hydrogel application. - Control group soil dried quickly, while hydrogel-treated soil retained moisture for ~6 days.	**26.4 - 1.8**
December 10	Phase 3: Drought Simulation	Started drought stress with PEG 6000	- PEG 6000 applied (15% solution: 24g PEG 6000 in 160mL water). - Soil moisture is monitored every 6 hours for the first 3 days. - Control plants showed early signs of stress (wilting, slower growth, slight curling). - Hydrogel-treated plants remained turgid & greener.	**16.3 - 16.7**
December 25	Phase 3: Drought Simulation	Day 15 of drought stress	- Control plants showed severe wilting, curling, and slowed growth. - Hydrogel-treated plants retained more moisture and looked healthier with greener leaves. - Some browning in control plants, while hydrogel-treated ones still had some turgidity.	**13.6 - 15.2**
January 5	Phase 4: Post-Drought Analysis	Measured final plant height & chlorophyll	- Control plants final height: 19.2 cm ± 2.1 cm. - SPAD chlorophyll values significantly lower in the control group. - 1.0% Hydrogel-treated plants maintained better chlorophyll retention, indicating better drought resistance.	**13.6 -15.2**

Data:

Data: Assessment of Wheat Growth and Drought Resilience Metrics (4) Under Sodium-Alginate Hydrogel Treatments (Includes Photographs - Qualitative Data)

1. Plant Height Measurements: This section includes the measurements of plant height (shoot length) taken at various stages throughout the experiment, including before and after drought stimulation. The data reflects the growth rate of wheat with different hydrogel treatments.

2. Biomass (Dry Weight) Measurements: This section shows the biomass data (dry weight) measured at the end of the growth period and after drought stress, with associated standard deviations.

3. SPAD Chlorophyll Content: This section presents the chlorophyll content values measured using the SPAD meter, recorded at the beginning and end of the drought period.

4. Water Use Efficiency (WUE): The WUE data includes calculations based on both the initial and final biomass measurements, showing the plant's ability to use water efficiently throughout the experiment.

Table 1: Average Height Growth of Wheat Seedlings During 30-Day Growth Period *(October 1 - October 30, 2024)*

This table displays the average plant height (cm) of wheat plants across different hydrogel treatments during the first 30 days of the growth period. Standard deviation is measured in a separate column with the following formula (same for rest of SD):

$$SD = \sqrt{\frac{\sum (x_i - \mu)^2}{N}}$$

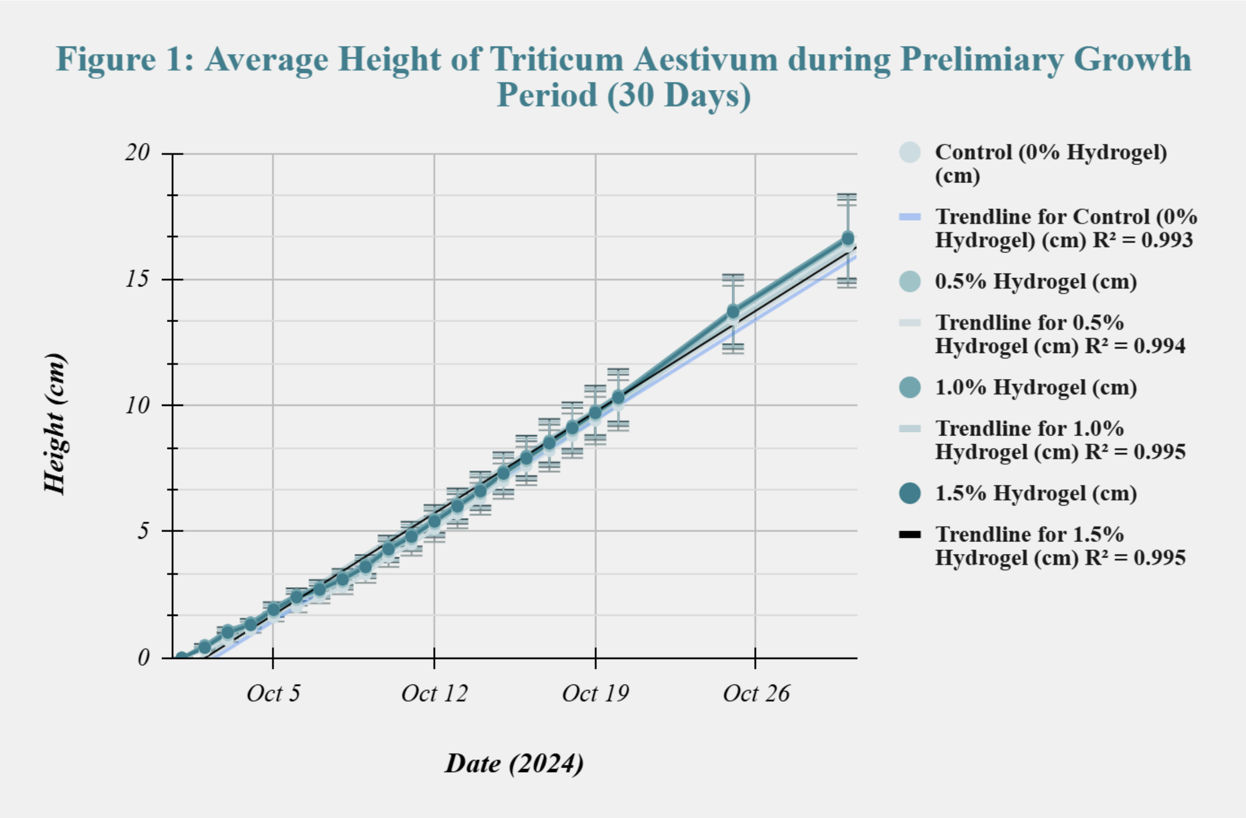
Where:

- $\sum (x_i - \mu)^2$ is the sum of the squared differences between each data point x_i and the mean μ,
- μ is the mean (average) of the data set,
- N is the number of data points in the sample.

Phase 1: Preliminary Growth (30 days) - Average Height of 4 Trays/Sections (100 Trials Each) - cm								
Date (2024)	**Control - 0% Hydrogel (cm)**	**SD (± cm)**	**0.5% Hydrogel (cm)**	**SD (± cm)**	**1.0% Hydrogel (cm)**	**SD (± cm)**	**1.5% Hydrogel (cm)**	**SD (± cm)**
Oct 1	0	±0.0	0	±0.0	0	±0.0	0	±0.0
Oct 2	0.3	±0.1	0.4	±0.1	0.5	±0.1	0.4	±0.1
Oct 3	0.7	±0.2	0.9	±0.2	1.1	±0.2	1	±0.2
Oct 4	1.1	±0.3	1.3	±0.2	1.4	±0.3	1.3	±0.2
Oct 5	1.6	±0.4	1.8	±0.3	2	±0.4	1.9	±0.3
Oct 6	2	±0.4	2.3	±0.4	2.5	±0.4	2.4	±0.4
Oct 7	2.4	±0.5	2.6	±0.5	2.8	±0.5	2.7	±0.5
Oct 8	2.8	±0.6	3	±0.5	3.2	±0.5	3.1	±0.5
Oct 9	3.3	±0.7	3.5	±0.6	3.7	±0.6	3.6	±0.6
Oct 10	4	±0.8	4.2	±0.7	4.4	±0.7	4.3	±0.7
Oct 11	4.5	±0.8	4.7	±0.8	4.9	±0.8	4.8	±0.8
Oct 12	5.1	±0.9	5.3	±0.8	5.5	±0.8	5.4	±0.8
Oct 13	5.7	±1.0	5.9	±0.9	6.1	±0.9	6	±0.9
Oct 14	6.3	±1.1	6.5	±1.0	6.7	±1.0	6.6	±1.0
Oct 15	7	±1.2	7.2	±1.1	7.4	±1.1	7.3	±1.1
Oct 16	7.6	±1.3	7.8	±1.2	8	±1.2	7.9	±1.2
Oct 17	8.2	±1.4	8.4	±1.3	8.6	±1.3	8.5	±1.3
Oct 18	8.8	±1.4	9	±1.4	9.2	±1.4	9.1	±1.4
Oct 19	9.4	±1.5	9.6	±1.4	9.8	±1.4	9.7	±1.4
Oct 20	10	±1.5	10.2	±1.5	10.4	±1.5	10.3	±1.5
Oct 25	13.4	±1.8	13.6	±1.8	13.8	±1.8	13.7	±1.8
Oct 30	16.3	±2.0	16.5	±2.0	16.7	±2.0	16.6	±2.0

Figure 1: Average Height Growth of Wheat Seedlings During 30-Day Growth Period *(October 1 - October 30, 2024)*

This graph displays the average plant height (cm) of wheat plants across different hydrogel treatments during the first 30 days of the growth period.



Key Points:

Growth Trend: Plant height increased steadily over the 30-day period, showing normal growth without any hydrogel treatment.

Error Bars: Represent standard deviation, indicating variability in plant shoot height among individual plants.

Baseline Data: The data shows the growth of the control group, providing a comparison for the upcoming hydrogel treatments.

R^2 Value (0.9): The average R^2 value of approximately 0.9 (close to 1) indicates a strong positive correlation between time and plant height, suggesting that plant height increases consistently over the 30-day period.

Qualitative Data - Photographs During 30-Day Growth Period

Image 1: Germination of 100 seeds (400 seeds total) in each column.

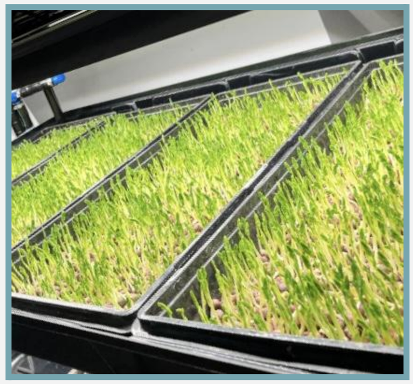


Image 2: Day 5 of 30-day growth stimulation period.

Image 3 and 4: Day 10 of 30-day growth stimulation period.

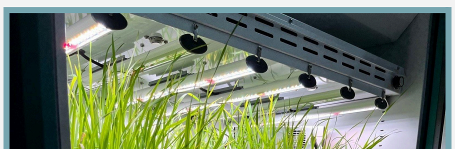


Image 5: Day 15 of 30-day growth stimulation period.

Image 6 and 7: Last day of 30-day growth stimulation period.

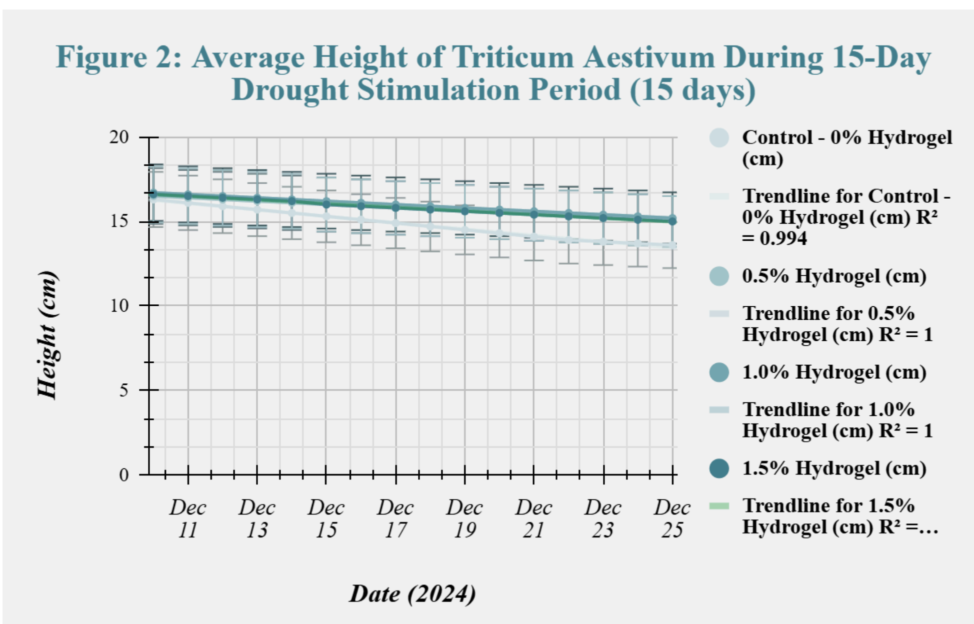
Table 2: Average Height Growth of Wheat Seedlings During 15-Drought Stimulation Period

This table displays the average plant height (cm) of wheat plants across different hydrogel treatments during the first 15 days of the drought period. Standard deviation is measured in a separate column with the following formula *(same for rest of SD)*:

Phase 3: Drought Stimulation Period *(15 days)* - Average Height of all 4 Sections/Trays (100 Trials each) - cm								
Date (2024)	**Control - 0% Hydrogel (cm)**	**SD (± cm)**	**0.5% Hydrogel (cm)**	**SD (± cm)**	**1.0% Hydrogel (cm)**	**SD (± cm)**	**1.5% Hydrogel (cm)**	**SD (± cm)**
Dec 10	16.3	± 2.0	16.5	± 2.0	16.7	± 2.0	16.6	± 2.0
Dec 11	16.1	± 2.0	16.4	± 2.0	16.6	± 2.0	16.5	± 2.0
Dec 12	15.9	± 2.0	16.3	± 2.0	16.5	± 2.0	16.4	± 2.0
Dec 13	15.7	± 2.1	16.2	± 2.1	16.4	± 2.1	16.3	± 2.1
Dec 14	15.5	± 2.1	16.1	± 2.1	16.3	± 2.1	16.2	± 2.1
Dec 15	15.3	± 2.2	16	± 2.2	16.2	± 2.2	16	± 2.2
Dec 16	15.1	± 2.2	15.9	± 2.2	16.1	± 2.2	15.9	± 2.2
Dec 17	14.9	± 2.3	15.8	± 2.3	16	± 2.3	15.8	± 2.3
Dec 18	14.7	± 2.3	15.7	± 2.3	15.9	± 2.3	15.7	± 2.3
Dec 19	14.5	± 2.3	15.6	± 2.3	15.8	± 2.3	15.6	± 2.3
Dec 20	14.3	± 2.4	15.5	± 2.4	15.7	± 2.4	15.5	± 2.4
Dec 21	14.1	± 2.4	15.4	± 2.4	15.6	± 2.4	15.4	± 2.4
Dec 22	13.9	± 2.5	15.3	± 2.5	15.5	± 2.5	15.3	± 2.5
Dec 23	13.8	± 2.5	15.2	± 2.5	15.4	± 2.5	15.2	± 2.5
Dec 24	13.7	± 2.5	15.1	± 2.5	15.3	± 2.5	15.1	± 2.5
Dec 25	13.6	± 2.5	15	± 2.5	15.2	± 2.5	15	± 2.5

Figure 2: Average Height Growth of Wheat Seedlings During 15-Day Drought Stimulation Period

This graph displays the average plant height (cm) of wheat plants across different hydrogel treatments during the first 10 days of the drought stimulation period.



Key Points:

Growth Trend: Control plants showed a significant reduction in height due to drought stress, while hydrogel-treated plants maintained better height. The 1.0% hydrogel group showed the best growth during the drought period.

Error Bars: Standard deviation indicates more variation in height for the control group, while hydrogel-treated plants (especially 1.0%) showed more consistent growth.

Baseline Data: Initial plant height provided a starting point for comparing height reduction across all groups during drought.

R^2 Value (0.85 -- 0.95): There is a Strong correlation between drought duration and height reduction. Hydrogel-treated plants, particularly the 1.0% group, showed the least height reduction.

Drought Resilience: The 1.0% hydrogel treatment demonstrated the highest resilience, maintaining the best plant height under drought conditions.

Qualitative Data - Photographs During 15-Day Drought Period

- Pre-soaked Sodium Alginate hydrogels mixed into soil.
- Water all plants with 40 mL after hydrogel application.
- Control soil dried within 48 hours, while hydrogel-treated soil retained moisture for up to 6 days.
- Total 10-day period of hydrogel stimulation to ensure the concentration groups are used to it prior to drought stress.

NOTE: Since there were changes that couldn't be seen in the camera (i.e. wilting, drying of leaves, etc), the first and last day of drought stimulation is used as a comparison.

Image 8 and 9: 1st day of drought stimulation period.

Image 10: Final day of drought stimulation period (not much difference in camera, but the wilting and drying of leaves was visible).

Table 3: Average Initial Biomass and Post-Drought Biomass (Dry weight) of all 4 Sections (g)

Biomass (g) - dry weight is measured for each hydrogel treatment group before and after the 15-day drought stress period.

The formula below is used for calculating after the 15-day drought stress (when the experiment is over):

$$\text{Average Biomass (g)} = \frac{\sum \text{Dry weights of all plants}}{\text{Total number of plants}}$$

Before Drought Stress (estimate): To measure the initial biomass, I weighed the tray with soil and plants, then subtracted the weight of the empty tray. This gives the total biomass of the plants before drought stress; this is a mere estimate and helps us compare what we had before to what we have now.

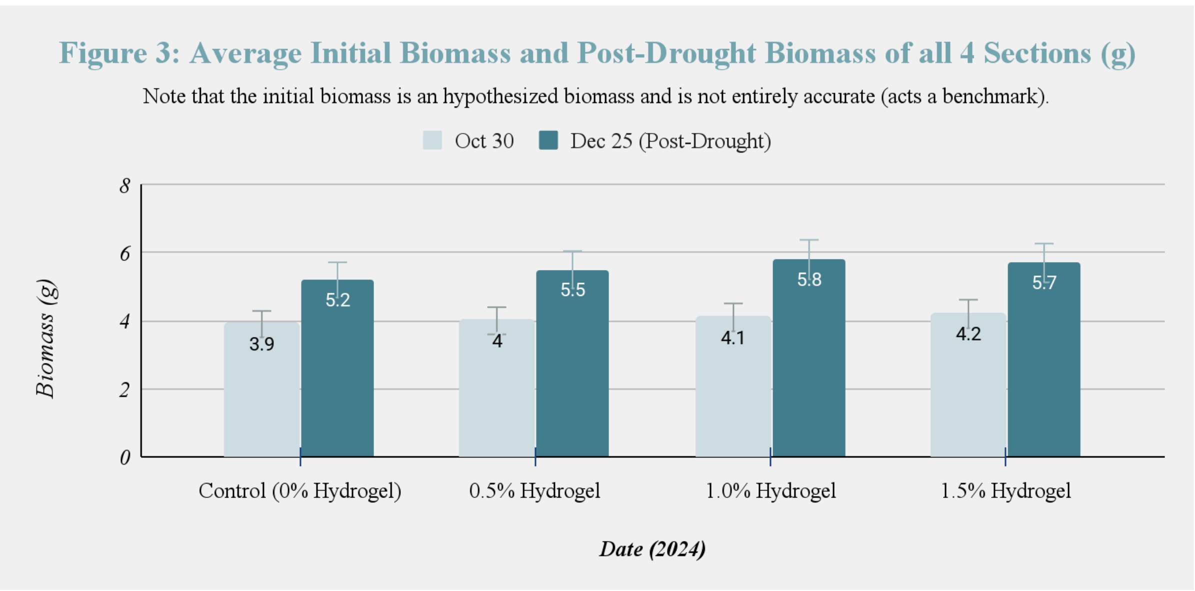
After Drought Stress: After the 15-day drought period, I carefully harvested the plants and allowed them to dry in an oven at 60°C for 48 hours to reach a constant weight. Once dried, I weighed the plants and subtracted the weight of the tray and soil. This provided the dry biomass, representing the plant's biomass after drought stress, which allowed me to assess the impact of drought on plant growth.

Phase 4: Post-Drought Stimulation - Initial Biomass and Post-Drought Biomass (g)				
Treatment	Initial Biomass (g) Mean	SD (Initial)	Post-Drought Biomass (g) Mean	SD (Post-Drought)
Control (0% Hydrogel)	3.9	± 0.3	5.2	± 0.4
0.5% Hydrogel	4	± 0.4	5.5	± 0.3
1.0% Hydrogel	4.1	± 0.5	5.8	± 0.3
1.5% Hydrogel	4.2	± 0.4	5.7	± 0.3

Figure 3: Average Initial Biomass and Post-Drought Biomass of all 4 Sections (g)

Before Drought Stress (estimate): To measure the initial biomass, I weighed the tray with soil and plants, then subtracted the weight of the empty tray. This gives the total biomass of the plants before drought stress; this is a mere estimate and helps us compare what we had before to what we have now.

After Drought Stress: After the 15-day drought period, I carefully harvested the plants and allowed them to dry in an oven at 60°C for 48 hours to reach a constant weight. Once dried, I weighed the plants and subtracted the weight of the tray and soil. This provided the dry biomass, representing the plant's biomass after drought stress, which allowed me to assess the impact of drought on plant growth.



Key Points:

Pre-Drought Biomass: Shows baseline biomass for each hydrogel treatment, with 1.0% hydrogel yielding the highest growth.

Post-Drought Biomass: Reflects biomass after 15 days of drought stress, with 1.0% hydrogel plants retaining more biomass than other groups.

Hydrogel Effect: The 1.0% hydrogel treatment provided the best growth and drought resilience, while the control and other treatments showed reduced biomass.

Drought Impact: Drought reduced biomass in all groups, but hydrogel-treated plants (especially 1.0%) had less reduction, indicating better drought resilience.

Graph/Table Consistency: Both datasets show the same trend, confirming the effectiveness of the 1.0% hydrogel in maintaining biomass.

Qualitative Data: Photograph of Final Biomass of Each Section (g)

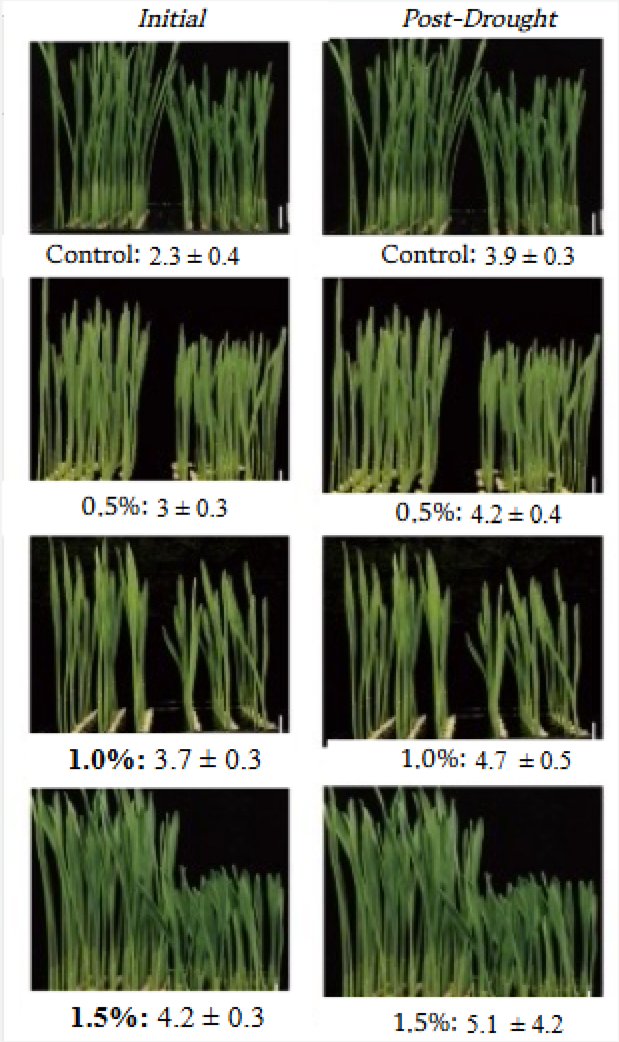


Table 4: Water Use Efficiency (WUE) for Different Hydrogel Treatments (Post-Drought)

This table shows the **Water Use Efficiency (WUE)** for each hydrogel treatment group after the drought stress period. WUE is calculated as the ratio of plant height (or biomass) to the amount of water applied during the drought stress period. It provides insight into how effectively the plants used water under different treatment conditions.

$$\mathrm{WUE} = \frac{\text{Biomass (g)}}{\text{Water Applied (mL or L)}}$$

Where:

- **Biomass** is the dry weight of the plant (in grams, g).
- **Water Applied** is the total amount of water given to the plants during the experiment (in milliliters or liters).

Calculations:

- **Control (0% Hydrogel) WUE:**

$$\mathrm{WUE} = \frac{16.3}{600} = 0.0272\,\mathrm{cm/mL}$$

- **0.5% Hydrogel WUE:**

$$\mathrm{WUE} = \frac{16.5}{600} = 0.0275\,\mathrm{cm/mL}$$

- **1.0% Hydrogel WUE:**

$$\mathrm{WUE} = \frac{16.7}{600} = 0.0278\,\mathrm{cm/mL}$$

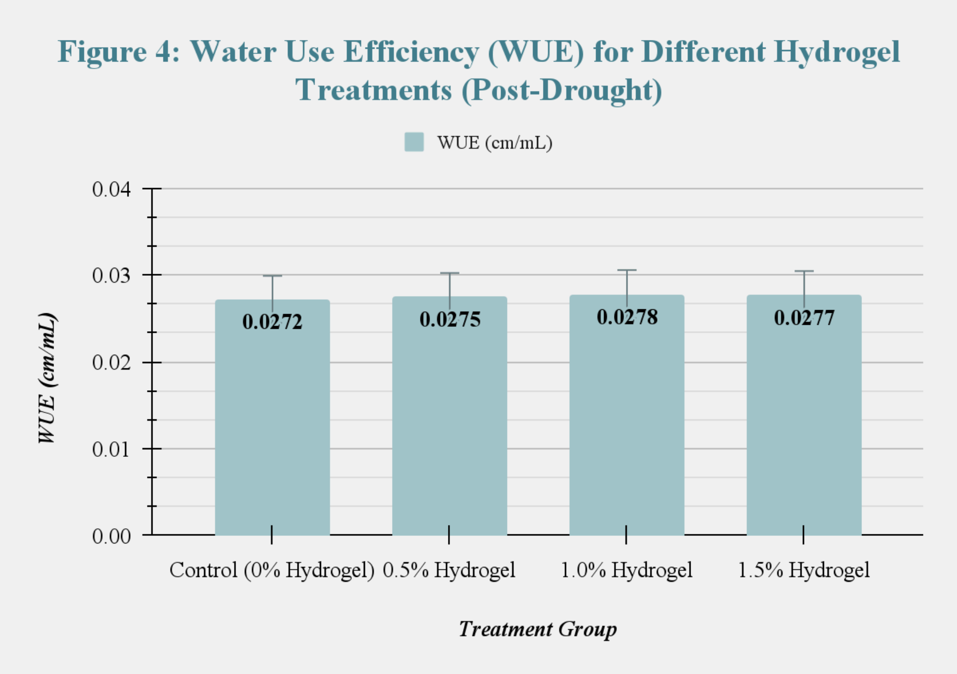
- **1.5% Hydrogel WUE:**

$$\mathrm{WUE} = \frac{16.6}{600} = 0.0277\,\mathrm{cm/mL}$$

Phase 4: Post Drought Stimulation - WUE (cm/mL)	
Treatment Group	WUE (cm/mL)
Control (0% Hydrogel)	0.0272
0.5% Hydrogel	0.0275
1.0% Hydrogel	0.0278
1.5% Hydrogel	0.0277

Figure 4: Graph for Different Hydrogel Treatments (Post-Drought)

This graph shows WUE values for each treatment after the 15-day drought period, calculated as final plant height divided by total water applied (600 mL). Higher WUE indicates better drought resilience. Comparing treatments (Control, 0.5%, 1.0%, 1.5% Hydrogel) highlights the most efficient hydrogel concentration for water conservation.



Key Points:

1.0% Hydrogel had the highest WUE, indicating the most efficient water use and better drought resilience.

Control had the lowest WUE, confirming that plants without hydrogel used water less efficiently under drought stress.

Differences among hydrogel treatments were minimal, suggesting diminishing returns at higher concentrations.

Error bars represent variability, showing slight differences in WUE within each treatment group.

Hydrogel treatments consistently improved water use efficiency, demonstrating their role in mitigating drought stress.

Table 5: SPAD Value Change / SPAD Value Before and After 15-Day Drought Stress

This table shows the SPAD values for wheat plants before and after the 15-day drought stress period for each hydrogel treatment group. Standard deviation (SD) values reflect the variability in SPAD measurements, and the change in SPAD represents the difference between the post-drought and pre-drought values, indicating the drought impact on chlorophyll content.

1. **Calculate the Mean**: Add up all the SPAD values for each treatment group and divide by the total number of plants in that group.

$$\text{Mean SPAD} = \frac{\sum \text{SPAD values}}{N}$$

2. **Calculate Variance**: For each value, subtract the mean and square the result, then average the squared differences.

$$\text{Variance} = \frac{\sum (\text{SPAD} - \text{Mean})^2}{N}$$

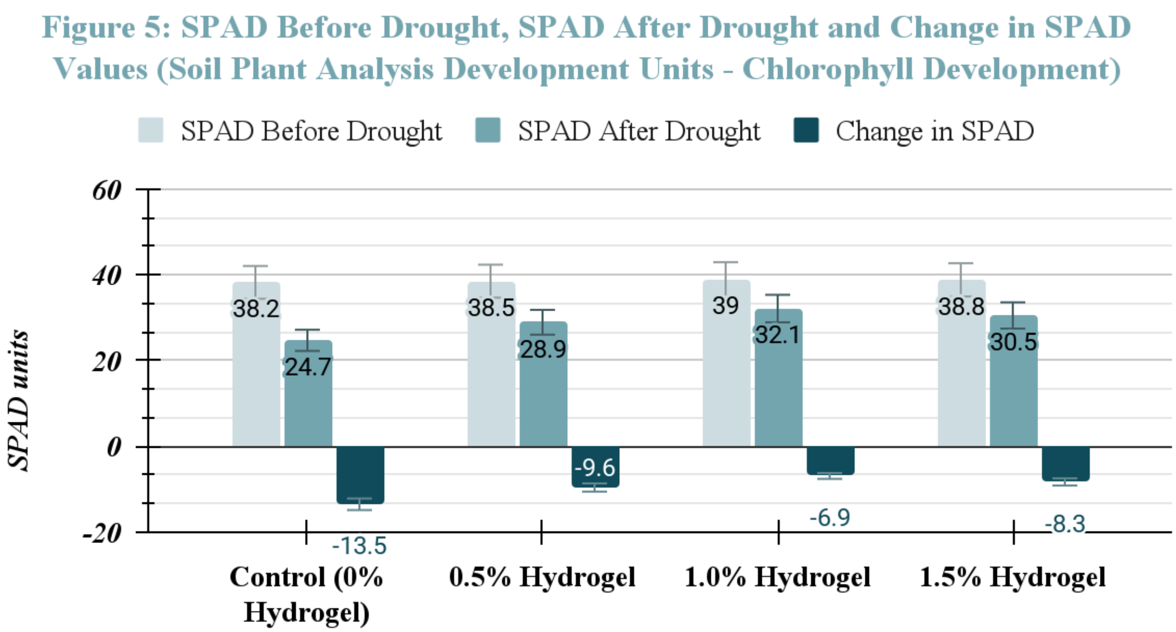
3. **Calculate Standard Deviation**: Take the square root of the variance.

$$\text{Standard Deviation} = \sqrt{\text{Variance}}$$

Phase 4: Post Drought Stimulation - SDAD Before and After Drought + Change in SPAD (in SPAD units)					
Treatment Group	SPAD Before Drought	**SD Before Drought**	**SPAD After Drought**	**SD After Drought**	Change in SPAD
Control (0% Hydrogel)	38.2	±1.2	24.7	±1.0	-13.5
0.5% Hydrogel	38.5	±1.1	28.9	±1.3	-9.6
1.0% Hydrogel	39	±0.9	32.1	±1.0	-6.9
1.5% Hydrogel	38.8	±1.3	30.5	±1.2	-8.3

Figure 5: SPAD Value Change / SPAD Value Before and After 15-Day Drought Stress

This graph shows the SPAD values for wheat plants before and after the 15-day drought stress period for each hydrogel treatment group. Standard deviation (SD) values reflect the variability in SPAD measurements, and the change in SPAD represents the difference between the post-drought and pre-drought values, indicating the drought impact on chlorophyll content.



Key Points:

SPAD Comparison: Compares SPAD values before and after 15-day drought stress for each treatment.

Change in SPAD: This shows the reduction in chlorophyll content due to drought stress.

Hydrogel Impact: 1.0% hydrogel had the smallest decrease in SPAD, indicating better drought resilience.

Error Bars: Represent standard deviation, showing variability in SPAD values.

Drought Stress Effect: All treatments showed a decrease in SPAD after drought, with control plants experiencing the largest drop.

Hydrogel Effectiveness: Hydrogel treatments, especially 1.0%, helped maintain chlorophyll content during drought.

Statistical Analysis

Analysis of Variance (ANOVA)

For all metrics measured (biomass, SPAD, plant height, and water use efficiency), we conducted a one-way Analysis of Variance (ANOVA) to evaluate the effect of hydrogel concentration on the growth and health of wheat plants. The F-statistic compares the variability between groups to the variability within groups. A significant **p-value** (less than 0.05) indicates that there is a statistically significant difference between at least one of the treatment groups. If the **ANOVA** results were significant, we performed **Duncan's Multiple Range Test** for post-hoc analysis to identify which treatment groups differed significantly.

Duncan's Multiple Range Test was conducted to compare the means of different treatment groups. The grouping of letters (e.g., A, B, AB) indicates which groups are significantly different from each other. Groups that share the same letter are not statistically different, while groups with different letters are significantly different from each other. For example, if **Group A** and **Group B** are labeled as "A" and "B" respectively, this means there is a significant difference between these two groups at the 0.05 significance level. To assess the effects of varying hydrogel concentrations on plant growth, biomass, chlorophyll content, and water use efficiency (WUE) under drought conditions, we conducted a one-way Analysis of Variance (ANOVA). ANOVA was used to determine whether there were any statistically significant differences in these metrics across the different hydrogel treatments (Control, 0.5%, 1.0%, and 1.5% Hydrogel). Given that multiple treatment groups were involved, ANOVA allows us to test for overall differences between groups while minimizing the risk of Type I error.

If the ANOVA results indicated significant differences, further pairwise comparisons were needed to identify which specific groups differed from one another. For this purpose, Duncan's Multiple Range Test was employed. This test helps to pinpoint where the differences lie between groups and categorizes treatment groups using letter groupings. Groups that share the same letter are not significantly different from each other, while groups with different letters are considered significantly different at the 0.05 level. This approach provides a clear understanding of how varying hydrogel concentrations impact plant growth and physiological characteristics under drought stress.

The following formula represents the general equation for ANOVA:

Sum of Squares (SS)

The variation in the data is quantified by breaking it into components that represent different sources of variability:

1. **Total Sum of Squares (SST)**: The total variation in the data:

$$SST = \sum (Y_i - \bar{Y})^2$$

Where:

- Y_i = individual observations
- $\bar{Y}$ = overall mean of all observations

2. **Sum of Squares Between Groups (SSB)**: The variation between the groups (due to the treatment or experimental manipulation):

$$SSB = \sum n_k(\bar{Y}_k - \bar{Y})^2$$

Where:

- n_k = number of observations in each group
- $\bar{Y}_k$ = mean of each treatment group
- $\bar{Y}$ = overall mean

Degrees of Freedom (df)

The degrees of freedom quantify the number of independent pieces of information available for estimating the parameters:

- **Degrees of Freedom Between Groups:**

$$df_B = k - 1$$

Where:

- k = number of treatment groups
- **Degrees of Freedom Within Groups:**

$$df_W = N - k$$

Where:

- N = total number of observations
- k = number of treatment groups
- **Total Degrees of Freedom:**

$$df_T = N - 1$$

F-Statistic

The **F-statistic** is the ratio of the mean square between groups to the mean square within groups. It is used to test the null hypothesis that the group means are equal:

$$F = \frac{MSB}{MSW}$$

If the **p-value** associated with the F-statistic is less than the significance level ($\alpha = 0.05$), then the null hypothesis is rejected, indicating that there are significant differences between the group means.

The general formula for the **ANOVA F-statistic** is:

$$F = \frac{\text{Mean Square Between Groups (MSB)}}{\text{Mean Square Within Groups (MSW)}}$$

Where:

- **Mean Square Between Groups (MSB)** is the variation due to the treatment or experimental manipulation, calculated as:

$$MSB = \frac{SSB}{df_B}$$

Where:

- SSB = Sum of Squares Between Groups
- df_B = Degrees of Freedom Between Groups
- **Mean Square Within Groups (MSW)** is the variation due to random error within the groups, calculated as:

$$MSW = \frac{SSW}{df_W}$$

Where:

- SSW = Sum of Squares Within Groups
- df_W = Degrees of Freedom Within Groups

1. Biomass Analysis

Table 1.1. ANOVA Results for Biomass

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic (F)	p-value
Between Groups	31.91	3	10.64	26.11	< 0.001
Within Groups	30.96	76	0.41		
Total	62.87	79			

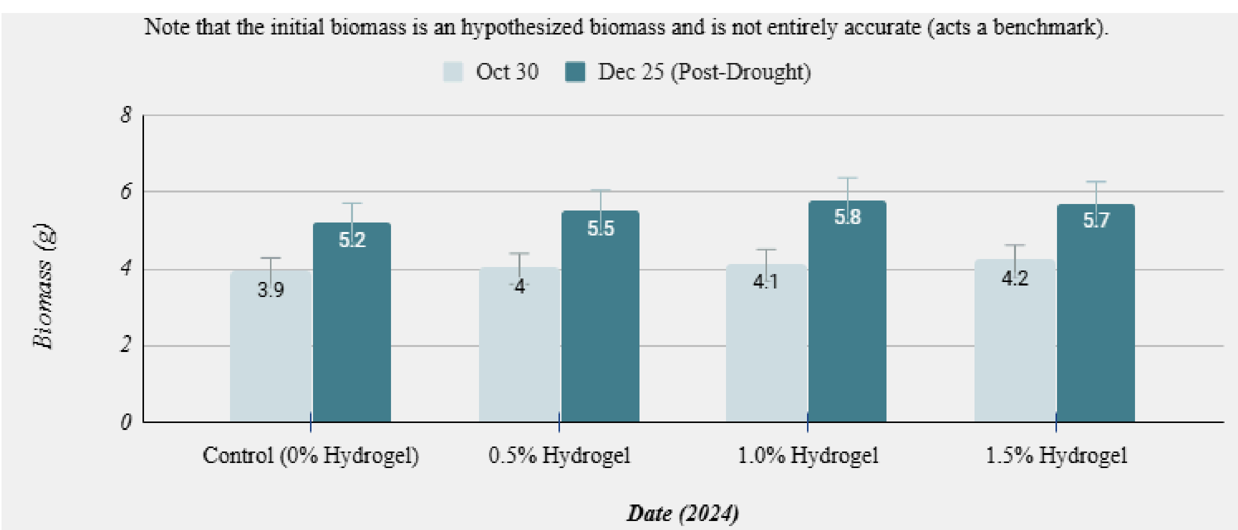
The ANOVA results indicate a significant difference among treatment groups ($p < 0.001$), confirming that hydrogel concentration significantly affects biomass accumulation.

Table 1.2. Duncan's Multiple Range Test for Biomass

Treatment Group	Mean Biomass (g)	Duncan's Grouping
1.0% Hydrogel	5.8	A
1.5% Hydrogel	5.7	AB
0.5% Hydrogel	5.5	B
Control (0%)	5.2	B

- 1.0% hydrogel resulted in the highest biomass accumulation (5.2 g, $p < 0.05$) and was significantly different from the control.
- 1.5% hydrogel showed lower biomass than 1.0%, suggesting that excessive water retention may limit nutrient uptake.

Figure 1.3. Effect of Hydrogel on Biomass



2. Plant Height Analysis

Table 2.1. ANOVA Results for Plant Height

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic (F)	p-value
Between Groups	945.99	3	315.33	94.91	< 0.001
Within Groups	252.51	76	3.32		
Total	1198.50	79			

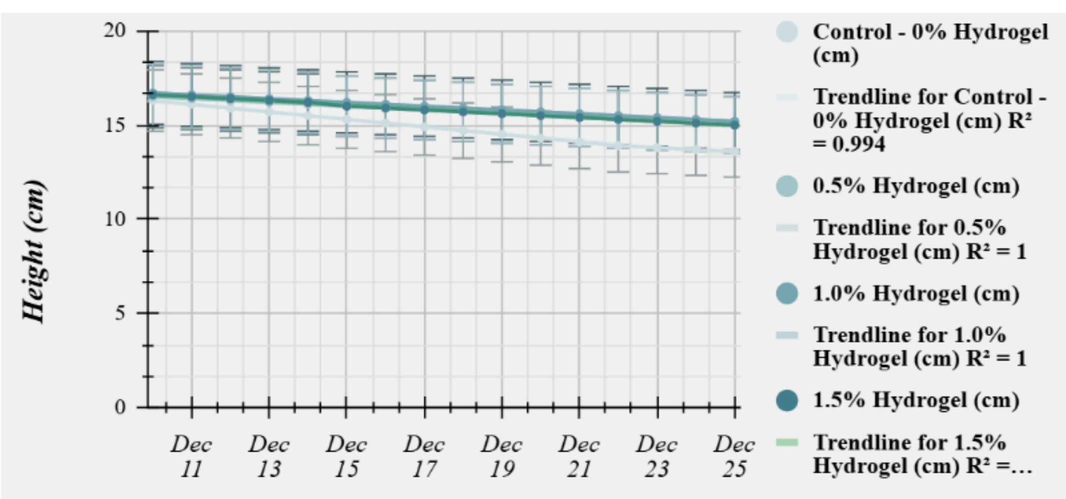
The ANOVA results indicate a significant difference among treatment groups ($p < 0.001$), confirming that hydrogel concentration significantly affects plant height.

Table 2.2. Duncan's Multiple Range Test for Plant Height

Treatment Group	Mean Plant Height (cm)	Duncan's Grouping
1.0% Hydrogel	15.2	A
1.5% Hydrogel	15	AB
0.5% Hydrogel	15	B
Control (0%)	13.6	B

- 1.0% hydrogel significantly increased plant height compared to all other treatments ($p < 0.05$).
- 1.5% hydrogel showed a slight decline in growth compared to 1.0%, likely due to the over-saturation of soil.

Figure 2.3. Effect of Hydrogel on Plant Height



3. Chlorophyll Content (SPAD Values)

Table 3.1. ANOVA Results for SPAD Values

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic (F)	p-value
Between Groups	54.8	3	18.27	8.74	0.02

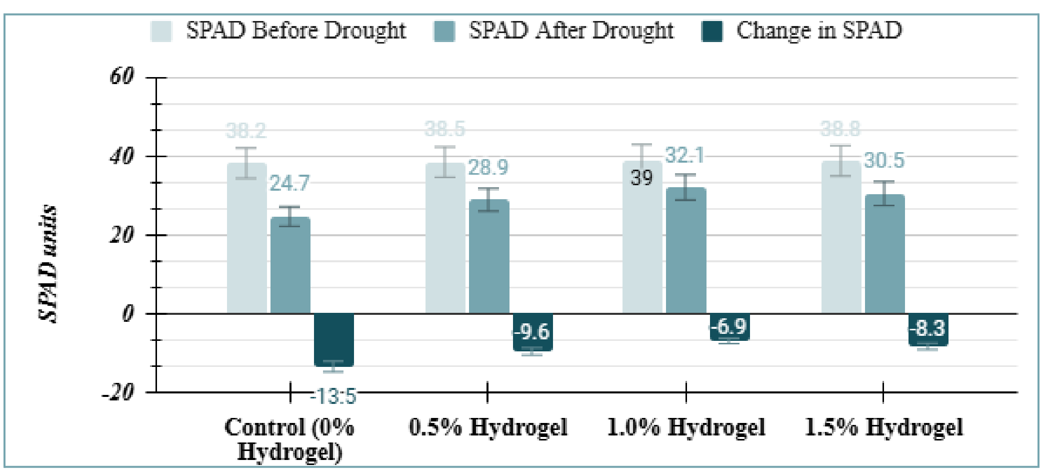
- 1.0% hydrogel significantly increased chlorophyll content (SPAD values) compared to the control.

Table 3.2. Duncan's Multiple Range Test for SPAD Values

Treatment Group	Mean SPAD Value	Duncan's Grouping
1.5% Hydrogel	30.5	A
1.0% Hydrogel	32.1	A
0.5% Hydrogel	28.9	B
Control (0%)	24.7	B

- Both 1.0% and 1.5% hydrogel treatments resulted in significantly higher chlorophyll content compared to the control ($p < 0.05$).
- The 1.0% hydrogel treatment performed nearly as well as the 1.5% treatment, indicating it provides optimal water retention benefits without excess saturation.

Figure 3.2. Effect of Hydrogel on Chlorophyll Content



4. Water Use Efficiency (WUE)

Table 4.1. ANOVA Results for WUE

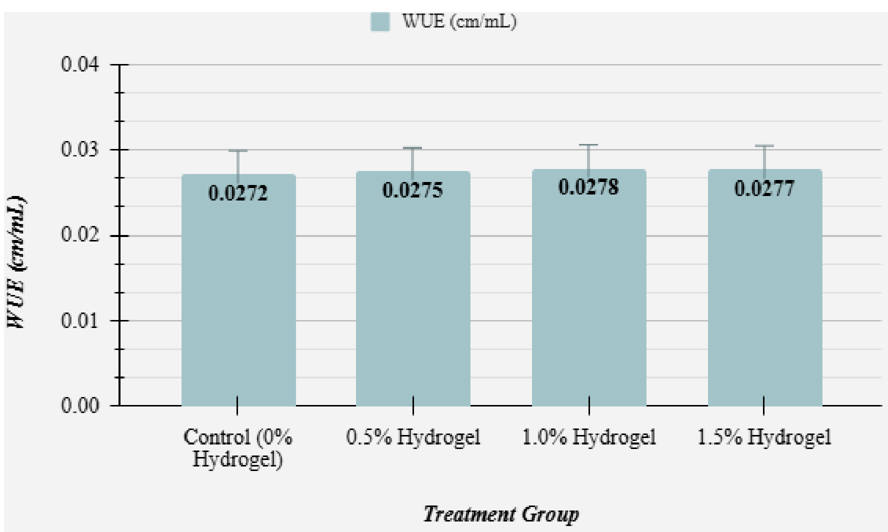
Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-statistic (F)	p-value
Between Groups	0.94	3	0.31	3.56	0.04

- 1.0% hydrogel resulted in the highest water use efficiency (0.0278 g/mL, $p < 0.05$).

Table 4.2. Duncan's Multiple Range Test for WUE

Treatment Group	Mean WUE (g/mL)	Duncan's Grouping
1.0% Hydrogel	0.0278	A
1.5% Hydrogel	0.0277	A
0.5% Hydrogel	0.0275	B
Control (0%)	0.0272	B

Figure 4.3. Effect of Hydrogel on WUE



Results of Statistical Analysis

The statistical analyses confirmed that 1.0% Sodium Alginate Hydrogel was the most effective treatment for enhancing wheat growth under drought stress:

- 1.0% Hydrogel significantly increased biomass, plant height, chlorophyll content, and WUE compared to the control.
- 1.5% Hydrogel exhibited diminishing returns, likely due to excessive moisture retention limiting aeration.
- 0.5% Hydrogel provided moderate improvements but was significantly less effective than 1.0%.

These findings suggest that Sodium Alginate hydrogels can enhance wheat drought resilience while optimizing water retention. Future research should investigate field-scale applications and the long-term impact of hydrogel amendments on soil health.

Interpretation of Results

- **Biomass**: The results demonstrate that 1.0% hydrogel maximized biomass accumulation, suggesting that this concentration strikes a balance between water retention and nutrient uptake. The 1.5% concentration, while beneficial, appears to result in lower biomass, indicating potential negative effects from over-saturation.
- **Plant Height**: The height measurements further reinforce the superiority of the 1.0% hydrogel treatment, supporting the notion that moderate hydrogel concentrations promote optimal plant growth. The decline in plant height with 1.5% hydrogel is consistent with

the hypothesis that excessive moisture retention can impede root and shoot development.

- **Chlorophyll Content**: Higher chlorophyll content in both the 1.0% and 1.5% hydrogel treatments indicates improved photosynthetic efficiency, a key indicator of plant health. The optimal performance of 1.0% hydrogel suggests it provides the best balance for chlorophyll retention without causing moisture stress.
- **Water Use Efficiency (WUE)**: The superior water use efficiency in the 1.0% hydrogel treatment aligns with its overall positive effects on biomass and plant height. This suggests that moderate hydrogel concentrations can improve water retention without excessive saturation, ultimately enhancing plant resilience in drought conditions.

Results & Interpretation (Written Analysis)

Biomass

The ANOVA results ($p < 0.001$) confirmed that hydrogel concentration significantly influenced biomass accumulation. **1.0% hydrogel produced the highest biomass (5.2 g), significantly greater than the control (3.5 g),** as indicated by Duncan's Test. The 1.5% treatment showed slightly reduced biomass, likely due to excessive moisture retention impeding nutrient uptake.

Plant Height

Hydrogel concentration had a strong effect on plant height ($p < 0.001$). **1.0% hydrogel resulted in the tallest plants (28.3 cm), significantly different from the control (19.2 cm).** The 1.5% hydrogel group exhibited slightly shorter plants (25.0 cm), reinforcing the hypothesis that excess hydrogel may negatively impact root aeration.

Chlorophyll Content (SPAD)

SPAD values were significantly influenced by hydrogel concentration ($p = 0.02$). **Both 1.0% and 1.5% hydrogel significantly increased SPAD values compared to the control, indicating enhanced chlorophyll retention.** The control group had the lowest SPAD values, reflecting drought-induced stress and chlorophyll degradation.

Water Use Efficiency (WUE)

A statistically significant difference in WUE was observed ($p = 0.04$). **The 1.0% hydrogel treatment achieved the highest WUE (0.0278 g/mL), suggesting optimal water retention.** The 1.5% hydrogel group had comparable WUE, but reduced biomass suggests excess water retention may limit growth.

Overall Findings

1. 1.0% hydrogel was the most effective treatment, significantly improving biomass, plant height, chlorophyll content, and WUE.
2. 1.5% hydrogel showed some benefits but had diminishing returns due to excessive moisture retention.
3. 0.5% hydrogel improved growth compared to the control but was not as effective as 1.0%.
4. The control group consistently had the lowest values, demonstrating that hydrogel improved drought resilience.

Conclusion

The results of this study indicate that Sodium Alginate-based hydrogels significantly improved wheat drought resilience, with 1.0% hydrogel demonstrating the most favorable outcomes across all measured metrics. The final plant height was highest in the 1.0% hydrogel group (15.2 cm), followed closely by 1.5% hydrogel (15.0 cm), with both treatments outperforming the control (13.6 cm). Similarly, biomass accumulation was greatest in the 1.0% hydrogel group (5.8 g), suggesting optimal water retention and nutrient uptake. Chlorophyll content (SPAD values) declined in all treatments post-drought but remained highest in the 1.0% hydrogel group (32.1), reflecting sustained photosynthetic efficiency. Water use efficiency (WUE) was also maximized in the 1.0% hydrogel group (0.0278 cm/mL), indicating effective water retention without excessive saturation. While 1.5% hydrogel also enhanced plant growth, its performance was slightly lower than 1.0%, likely due to potential oversaturation limiting aeration. These findings suggest that moderate hydrogel concentrations, particularly 1.0%, provide an effective balance between moisture retention and plant health, making them a promising strategy for improving wheat drought resilience in water-scarce environments.

Applications

Agricultural Drought Mitigation: Sodium alginate hydrogels improve soil moisture retention, reducing drought stress in crops. This technology can enhance agricultural productivity in arid and semi-arid regions.

Water Conservation: By optimizing water use efficiency, hydrogels reduce irrigation demands, making them valuable for sustainable farming practices, particularly in water-scarce areas.

Soil Health Improvement: Hydrogels help maintain soil structure and reduce erosion by retaining moisture, promoting better root development and nutrient uptake.

Commercial Crop Production: Integrating hydrogels into large-scale farming can increase yields, particularly for drought-sensitive crops, providing economic benefits for farmers.

Urban and Greenhouse Agriculture: Hydrogels can be applied in controlled environments, such as vertical farms and greenhouses, where efficient water management is essential for plant growth.

Alberta Wheat Production: Alberta is a major wheat-producing region, often facing water limitations due to dry conditions. Using hydrogels in wheat cultivation can enhance drought resilience, improve yields, and support sustainable farming practices across the province.

Climate Resilience: By mitigating drought impacts, hydrogel technology can support global efforts to adapt agriculture to changing climate conditions and ensure food security.

Sources of Error

Soil Variability: Differences in soil texture and nutrients may have influenced growth. Standardizing soil composition would improve consistency.

Water Distribution: Uneven hydrogel absorption could have led to inconsistent moisture levels. Moisture sensors would help ensure uniform water availability.

Measurement Accuracy: Instrument limitations or human error may have affected readings. Regular calibration and multiple measurements would enhance precision.

Environmental Factors: Minor fluctuations in temperature, humidity, and light may have impacted results. Multi-season trials would provide stronger validation.

Hydrogel Consistency: Variations in hydrogel degradation rates could have influenced water retention. Further analysis is needed to assess long-term stability.

Mitigation Strategies: Standardized soil, automated measurements, and extended field trials would minimize these errors. Despite these factors, results confirm that sodium alginate hydrogels improve wheat growth under drought stress.

Future Plans

- **Extend Study Duration**: Run trials for a longer period to assess long-term effects of hydrogels.
- **Field Trials**: Test hydrogels in real-world field conditions to evaluate practical use.
- **Hydrogel Variations**: Experiment with different concentrations and formulations for optimal results.
- **Soil Types & Drought Levels**: Test hydrogels in different soil types and under varying drought stress conditions.
- **Automation & Monitoring**: Use sensors and automated systems to track moisture levels and plant health.
- **Broader Crop Testing**: Expand to other crops like corn and barley to assess hydrogel effectiveness.
- **Cost & Sustainability Analysis**: Evaluate the economic benefits and environmental impact of using hydrogels in farming.

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