Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/20799
DOI URL: http://dx.doi.org/10.21474/IJAR01/20799

RESEARCH ARTICLE

COMPARATIVE EFFICACY OF VARIOUS SUPERABSORBENT POLYMERS (SAPs) IN ENHANCING SOIL MOISTURE RETENTION AND PLANT GROWTH

Maricel T. Gubat[1], Naira S. Sali[2], Michelle Jewel R. Balita[2], Pauline Claire S. Oriondo[2], Angel Alexie M. Laspobres[2], Ma. Dominique Christia A. Salonga[2], Benj Sebastian B. Jalandoni[2] and Ma. Athena M. Ramos[2]

1. Researcher Supervisor, Senior High School Department, Philippine School Doha, Doha State of Qatar.
2. Research Student, Senior High School Department, Philippine School Doha, Doha State of Qatar.

……………………………………………………………………………………………………....

Manuscript Info

……………………….

Manuscript History
Received: 15 February 2025
Final Accepted: 19 March 2025
Published: April 2025

Key words:-
Superabsorbent polymers, Potato starch, Chitin, Plant growth, Soil moisture retention

Abstract

………………………………………………………………….
Superabsorbent polymers (SAPs) are practical in agriculture since they improve soil health and water retention, especially in areas with limited water resources. However, most commercial SAPs are non-biodegradable and raise environmental concerns, makingshrimp *(Caridea)*shell waste and potato *(Solanum tuberosum)* peels ideal materials for developing organic SAPs. **Methodology:** A quantitative experimental research design was employed to compare the efficacy of biodegradable superabsorbent polymers. This study adopts this method as it provides a systematic framework for testing the effectiveness of the organic SAPs. **Results:** Setup C, treated with mixed SAP, experienced the least water loss, while the controlled group underwent the most when compared by weight. All SAP-treated plants only lost 20-40% of their moisture after 24 hours, with the least retention in the control group, which lost half. Setup C showed the best overall growth among the SAP-treated plants, including height difference, leaf count, flower development, and fruit yield. The treated plants displayed healthy overall plant health, while the control group lacked in aspects of color, leaf size, and stem condition. **Discussion:** The incorporation of SAPs reduced water loss and retained moisture within the soil of the treated plants. An increase in all aspects of plant growth was observed, especially in the mixed SAP set-up. Visually, the plants exhibited healthy features, from their leaf color to growth uniformity. **Conclusion:** Shrimp shell waste and potato peel-based SAPs effectively conserve water moisture and improve plant health to promote further growth.

……………………………………………………………………………………………………....

Corresponding Author:-Maricel T. Gubat
Address:-Philippine School Doha, Doha, State of Qatar.

Introduction:-

Superabsorbent polymers hold significance in the daily lives of people as they are widespread in different fields, such as healthcare products, agriculture, horticulture, construction, engineering, and many more (Chen et al., 2022). Superabsorbent polymers are widely used as containers for water and plant nutrients, especially in arid and semiarid regions, since they significantly improve water usage efficiency (Krasnopeeva et al., 2022). Therefore, they can be used as an amendment for soil health improvement, ultimately improving water holding capacity and plant available water (Malik et al., 2022).

In spite of the water resource scarcity crisis, embracing water-saving agricultural practices is critical for assuring the sustainable development of communities. Additionally, the anticipated impact of climate change is an increase in the severity of droughts (Gornall et al., 2010, as cited in Dehkordi, 2016). Most commercial superabsorbent polymers have low biodegradability, making them environmentally unfriendly in the long run (Dehkordi, 2016). Superabsorbent polymers are frequently produced from acrylic acid and acrylamide solution or inverse-suspension polymerization techniques, which are non-biodegradable and are harmful to the environment, causing pollution (Sudhakar et al., 2021). Since superabsorbent polymers are naturally not compostable, this waste poses a critical environmental problem, indicating that developing eco-friendly and biodegradable superabsorbent polymers is urgent (Whang et al., 2021).

Natural polymers have undoubtedly become interesting because they can be obtained from abundant, renewable, and easily accessible natural sources (Rajeswari et al., 2017). Furthermore, natural polymers are made from natural materials, such as plants and animals, without harming the environment or humans. In contrast, synthetic polymers manufactured by chemical processes harm both in the long run (Srivastava & Abul Kalam, 2019).

Superabsorbent polymers are cross-linked polymer networks formed by water-soluble components, which can absorb a notable amount of water relative to their mass without dissolving. The properties present in superabsorbent polymers allow them to be manipulated extensively across fields (Ostrand et al., 2020). Superabsorbent polymers made with synthetic polymers can absorb and retain substantial amounts of aqueous solutions. These polymers can act as hydrogels and quickly and efficiently store water when contact occurs (over 300 times their volume), allowing them to be placed in agricultural areas to retain the water until it reaches the roots of plants (Rappoport, 2024). Moreover, superabsorbent polymers, typically consisting of acrylamide, acrylic acid, and associated salts, are marketed in a wide range of products with varying types and properties(Ostrand et al., 2020). Superabsorbent polymers have great potential for water absorption because of their large surface area and the improved accessibility of aqueous liquids to the hydrophilic groups of the polymer backbone (Bachra et al., 2023).

Studies have collated findings that using natural and biodegradable polymers in manufacturing superabsorbent polymers has increased due to growing environmental concerns, especially in agriculture. Natural polymers are far more environmentally beneficial and efficient than synthetic ones (Supare&Mahanwar, 2022). Significant benefits of natural polymers include their water solubility, emulsifying, gelling, binding, and biodegradability, as well as their positive biological performance (Kandar et al., 2021). Hydrogels are superabsorbent polymers capable of retaining plant nutrients and water as the surrounding soil dries out; they increase water use efficiency and irrigation intervals, decrease irrigation costs, and provide plants with the required nutrients and moisture (Oladosu et al., 2022).

Chitin is one of the most abundant yet low-cost renewable biopolymers obtained from marine sources (Singh et al., 2017). It is extracted mainly from the cuticles of various crustaceans, principally crabs and shrimp (Yan et al., 2023). These hydrogels are an effective tool for agricultural applications due to their excellent water-holding capacity and controlled fertilizer release ability (Tariq et al., 2023). With this, superabsorbent polymers composed of organic materials, like shell wastes, will be able to contribute to environmental sustainability, unlike the predominantly non-biodegradable microbeads that are strenuous to recycle. Superabsorbent polymers represent a class of organic chemicals defined primarily by their functional capability rather than their chemical structure. Organic superabsorbent polymers are naturally derived substances, and when mixed with soil, they help to retain water for a longer time (Shome et al., 2018). Maghsoudi et al. (2020) state that natural polymers are readily available and cheaper. Utilizing organic superabsorbent polymers as an alternative will allow them to perform like synthetic superabsorbent polymers while being environmentally friendly and sustainable.

The seafood industry produces waste, such as shells, bones, and wastewater. The discards are nutrient-dense, with varied levels of carotenoids, proteins, chitin, and other minerals. Thus, it is critical to subject seafood trash, particularly shrimp waste, to secondary processing and valorization for demineralization and deproteinization to recover industrially necessary chemicals (Wani et al., 2023). "Green Chemistry" investigates the remediation of hazardous crab shell waste for the environmentally friendly production of bacterial alkaline phosphatase (ALP) using bioprocessing development methodologies, emphasizing the need for good waste management in the seafood industry (Abdelgalil& Abo-Zaid, 2022).

Potato peels are one of the massive amounts of waste thrown daily, making them a potential material to be transformed into a7 superabsorbent polymer. They increase soil fertility, contain starch, and have similar properties to gelling agents that can absorb large amounts of water as a superabsorbent polymer. It is an abundant carbohydrate polymer, biodegradable, and a renewable raw resource with good chemical stability and high reactivity (Supare&Mahanwar, 2022). Starch-based polymeric hydrogels exhibit good water-holding capacity and biodegradability, which makes them a potential candidate for agricultural use (Tariq et al., 2023). Additionally, potato peels contain pectin, a polysaccharide composed of galacturonic acid in the cell membrane of a plant. Polysaccharides are not only renewable but also have economic advantages over synthetic ones (Coviello et al., 2007). The potato peel contains phytochemicals that act as potent antioxidants and nutrient donors (Sudhakar et al., 2021). The potato SAP acts nearly as a good “gelling agent” that possesses the power to soak up a great quantity of water (Sudhakar et al., 2021).

Previous studies have investigated the potential alternatives for commercial superabsorbent polymers because of the environmental, health, and safety hazards they entail. It addresses the issues linked to existing industrial practices, such as the application of corrosive reagents, the destructive removal of functional components, and the production of substantial waste (Yang et al., 2019). Furthermore, there are concerns about toxicity resulting from their agricultural use or applications related to human consumption; therefore, they have been identified as potential soil pollutants (Oladosu et al., 2022). Organic superabsorbent polymers made of shrimp shell wastes and potato peels have been created and tested separately in different locations. This study sought to formulate organic superabsorbent polymers made of shrimp shell waste and potato peels and compare the efficacy of the two superabsorbent polymers when separated and combined. Furthermore, a gap in the location of the study is evident, as this study was conducted in Doha, Qatar.

This study strived to advance Qatar's goal for development in the environmental sector, promoting a balance between economic growth and environmental protection. This research aids Qatar by advancing water conservation and enhancing agricultural productivity while preserving the environment. The findings help reduce ecological concerns and strengthen sustainability as the production of superabsorbent polymers utilizes organic materials, specifically shrimp shell waste and potato peels.

Methods:-

Research Method & Research Design:

This study employed an experimental research design that follows a scientific research design wherein an independent variable and dependent variable are manipulated, measured, and calculated in a controlled environment (Singh, 2021). In this study, shrimp shell wastes and potato peels were the independent variables, and moisture retention and plant growth were the dependent variables. An experimental research design allows the accurate measurement of the dependent variable using scientific tools and thorough data collection (Zubair, 2023), which includes calculating changes in water moisture and monitoring average increases in height, leaf count, flower count, and fruit yield in this study.

Research Locale

The study was conducted at the researchers' school, Doha, State of Qatar, specifically in the Messaimeer Area (Zone 56), Al Khulaifat Al Jadeeda Street (St. 1011); in addition to being students there, the researchers needed the school's facilities in the creation of their work.

Research Procedure

The procedure demonstrates the in-depth process of creating a superabsorbent polymer using shrimp shell waste and potato peel. It was based on Sudhakar et al. (2021), Gómez-Estaca et al. (2023), and Maschmeyer et al. (2020)'s research and modified to correspond with this study's findings.

Making Potato Peel SAP

1. Gather all the materials and equipment needed for the experiment.
2. Wear gloves while handling the food scraps to prevent contamination.
3. Wash and air-fry 200 grams of potato peels.
4. Pan-fry the dried potato peels for 15-20 minutes.
5. Finely chop the potato peels into square pieces.
6. Add coconut powder to dried peels and mix thoroughly.
7. Set aside the potato SAP.

Making Shrimp Shell Waste SAP

1. Gather all the materials and equipment needed for the experiment.
2. Wear gloves while handling the food scraps to prevent contamination.
3. Thoroughly wash 400 grams of shrimp shells.
4. Air-fry the shrimp shells for 10 minutes at 240 °C.
5. Grind the shrimp shells using a food processor.
6. Deproteinize the shrimp shells in a pressure cooker with 500 milliliters of hot water at 180 °C for 30 minutes.
7. Soak the remaining solids in 60.5 milliliters of lactic acid solution for 72 hours at room temperature to demineralize.
8. Wash and drain the extracted chitin.
9. Transfer the chitin to a baking pan to dry.
10. Set aside the shrimp SAP.

Making Potato Peel-Shrimp Shell SAP

1. Divide 15 grams of chitin SAP and 15 grams of potato peels SAP.
2. Combine both the chitin SAP and potato peels SAP in a bowl.

   A total of 3 organic superabsorbent polymers is the final product.

Preparing the soil with Organic Superabsorbent Polymer

1. Prepare three pots with three kilograms of soil in each.
2. Incorporate 30 grams of shrimp SAP, 30 grams of potato peels SAP, and 30 grams of combined shrimp and potato peels SAP in 3 separate pots of soil, respectively.
3. Keep one pot with no SAP to serve as the control group.

Results

This section presents the results and interpretations of the data collected during the testing procedure. It showcases the progression of the different growth factors of the tomato plants with the varying superabsorbent polymer treatments over a four-week observation period. Moreover, it displays the water absorption capacity observed in every setup. The visual assessments of the plants are also indicated for the measurement of overall plant health.

1. The effectiveness of organic superabsorbent polymers in the growth of tomato in terms of plant height, leaf count, flower and fruit yield

Table 1.1

Comparison of Height Difference in Tomato Plants Across Different Treatments

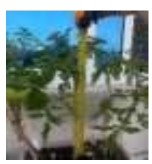
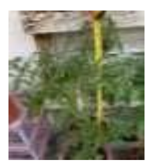
	(Set up A)Shrimp Shell Wastes SAP	**(Set up B)Potato Peels SAP**	**(Set up C)Shrimp Shell Wastes and Potato Peels SAP**	**(Set up D)Controlled Plant**
Photos				
Week 1	**37.0 cm**	**42.0 cm**	**67.5 cm**	**36.0 cm**
Photos				
Week 2	**42.0 cm**	**45.1 cm**	**72.0 cm**	**39.6 cm**
Photos				
Week 3	**51.0 cm**	**49.0 cm**	**80.0 cm**	**39.0 cm**
Photos				
Week 4	**52.0 cm**	**50.0 cm**	**82.5 cm**	**39.3 cm**
Height Difference	**15 cm**	**8.0 cm**	**15 cm**	**3.3 cm**

Table 1.1 shows the height difference of the plants after four weeks with different superabsorbent polymer applications compared to a control group. Each setup was prepared with three kilograms of soil in pots of the same size and watered with 750 milliliters. Setup A was treated with the shrimp SAP, setup B with potato SAP, setup C with the mixed SAP, and setup D contained no SAP. To attain the height difference, the final height from week four was subtracted from the initial height recorded in week one. In the testing process, the plant height was measured in centimeters using a measuring tape to determine the weekly height increase of the plant. Setup A displayed a 15-cm increase, Setup B showed 8.0 cm, Setup C showed a 15-cm growth, and the controlled plant grew 3.3 cm.

In evaluating the overall plant development, plant height is an important determinant of biomass accumulation and photosynthetic ability. The two factors help establish plant productivity and its adaptation to specific conditions, either environmentally or genetically (Liu& Chen, 2018). Monitoring the plant height may correlate with the observation of growth patterns that reflect the success of a certain cultivation practice. Shoot height was observed to have an increasing trend, where greater superabsorbent polymer applications could further pronounce its direct effects (Seven et. al, 2024). Similarly, the recorded increase in plant heights brought by SAPs signifies its benefits to plant productivity. Setups A and C resulted in the highest height increase, with 15 cm growth, implying better water retention caused by the presence of SAPs. Compared to the control group, setup B still produced greater height, demonstrating the importance of SAPs in improving irrigation methods.

Chitin contributes to plant growth as it is highly biocompatible, biodegradable, and non-toxic (Casadidio et al., 2019). Since chitin is a biopolymer, it has great prospect for use in retail and industrial applications, most especially in plant cultivation. Chitin acts as a growth stimulator and greatly benefits agricultural products such as fertilizers, soil conditioning agents, and plant disease control agents (Shamsina et. al, 2019). The presence of shrimp SAP in the setups that displayed the highest height difference implies the contribution of chitin to the vertical growth of the tomato plants.

Table 1.2*Comparison of Leaf Count in Tomato Plants Across Different Treatments*

	(Set up A)Shrimp Shell Wastes SAP	**(Set up B)Potato Peels SAP**	**(Set up C)Shrimp Shell Wastes and Potato Peels SAP**	**(Set up D)Controlled Plant**
Photos				
Leaf count at Week 1	**378 pcs**	**85 pcs**	**452 pcs**	**339 pcs**
Photos				
Leaf count at Week 2	**429 pcs**	**113 pcs**	**656 pcs**	**368 pcs**
Photos				
Leaf count at Week 3	**461 pcs**	**117 pcs**	**492 pcs**	**374 pcs**
Photos				
Leaf count at Week 4	**472 pcs**	**122 pcs**	**487 pcs**	**380 pcs**
Average Leaf Count	**435 pcs**	**109 pcs**	**522 pcs**	**365 pcs**

Table 1.2 shows the increasing number of leaves of the tomato plant using various superabsorbent polymers. With the measurements taken over four weeks, all leaf counts were added, then divided by four to get the average of each setup. Comparing the number of leaves from week one to week four, the following averages were incurred: shrimp SAP with

435 leaves, potato SAP with 109 leaves, mixed SAP with 522 leaves, and the controlled plant with 365 leaves. However, it is notable that the mixed SAP setup displayed a rapid growth of leaves from weeks one to two. The leaf count within a plant indicates its overall health as it reflects the plant's photosynthetic ability, vigor, and potential to produce biomass. Leaf count is a valuable indicator in determining plant success in controlled and field environments since it correlates with the behavior of the plant to environmental factors, such as light, temperature, and water availability (Hossain & Ali, 2017). The mixed SAP mixture had the highest leaf count, indicating that nutrients and water were made much more available with the combination of both the shrimp and potato SAPs. With this, the development of leaves became more rapid due to consistent photosynthesis capabilities. The shrimp SAP followed with moderate benefits shown in its leaf count. Chitin and chitosan are natural polysaccharides that serve as a sustainable substitute for crop production due to their structure and size (Li et al., 2020). Additionally, starch from potatoes is a natural polymer, making it an ideal component of biodegradable sorbents. (Schmidt et al., 2024). The study highlighted the sorption properties of starch polymers and water-swelling abilities. In addition, potato peels also provide compostable benefits that ensure their harmless impacts on the environment.

The application of extracted chitin present in setups A and C signifies how it benefits plant growth in terms of leaf production. Meanwhile, the potato SAP displayed a minimal increase. The use of the various SAPs indicates that the chitin found in shrimps and the starch polysaccharide from the potato peels contribute to the health of the plant by supporting its leaf growth.

Table 1.3 ***Comparison of Flower Development in Tomato Plants Across Different Treatments***

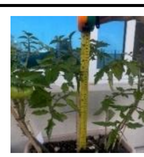
	(Set up A)Shrimp Shell Wastes SAP	(Set up B)Potato Peels SAP	(Set up C)Shrimp Shell Wastes and Potato Peels SAP	(Set up D)Controlled Plant
Photos				
Flower count at Week 1	**0 pcs**	**1 pc**	**12 pcs**	**0 pcs**
Photos				
Flower count at Week 2	**3 pcs**	**2 pcs**	**39 pcs**	**0 pcs**
Photos				
Flower count at Week 3	**6 pcs**	**0 pc**	**7 pc**	**0 pcs**
Photos				
Flower count at Week 4	**9 pcs**	**0 pcs**	**0 pcs**	**0 pcs**
Average flower count	**5 pcs**	**2 pcs**	**15 pcs**	**0 pcs**

Table 1.3 displays the weekly progress in the number of flowers from the tomato plant using the organic superabsorbent polymers. Setup A started with zero flowers, then three the following week, with an increase reaching nine flowers, giving an average count of five. Meanwhile, Setup B barely increased in the number of flowers, having only a mean of two flowers. The setup C showed an increasing pattern from weeks one to two, but slowly led to a decrease in the flower count, ending up with a 15-flower average. On the other hand, Setup D did not observe any flower growth throughout the entire month.

Flowers are essential in the life cycle of a plant for it to produce fruits and germinate seeds. A key indicator of plant health and adaptability is seen in the ability of a plant to develop flowers with proper timing, quality, and quantity (Sharma & Gupta, 2019). Multiple factors affect the presence of flowers in plants, including nutrient availability, water stress, and light conditions. In another study observing the effects of plant-based superabsorbent polymers on tomato growth, the greatest flower count was seen in the setup containing SAPs, which indicates better tomato performance when treated (Kathi et al., 2021). Similarly, setups A, B, and C observed flower growth, with setup C showing the greatest number of flowers. The presence of flowers within the plant implies that it will have the potential to increase its fruit yield and continue its regular reproductive processes. With Setup C displaying the highest flower count compared to the rest, it shows the contribution of the properties of combined shrimp and potato in increasing flower development.

Table 1.4*Comparison of Fruit Yield in Tomato Plants Across Different Treatments*

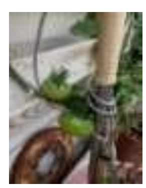
	(Set up A)Shrimp Shell Wastes SAP	**(Set up B)Potato Peels SAP**	**(Set up C)Shrimp Shell Wastes and Potato Peels SAP**	**(Set up D)Controlled Plant**
Photos				
Fruit count in Week 1	**0 fruits**	**1 fruit**	**2 fruits**	**0 fruits**
Photos				
Fruit count in Week 2	**0 fruits**	**2 fruits**	**3 fruits**	**0 fruits**
Photos				
Fruit count in Week 3	**0 fruits**	**2 fruits**	**3 fruits**	**0 fruits**
Photos				
Fruit count in Week 4	**0 fruits**	**2 fruits**	**3 fruits**	**0 fruits**
Average fruit count	**0 fruits**	**2 fruits**	**3 fruits**	**0 fruits**

Table 1.4 compares the effects of different superabsorbent polymers on tomato fruit yield. The average was taken from the number of fruits recorded weekly, specifically by adding all counts from the first to the last week and dividing the total by four. The data further illustrates the observed increase in fruit production with the SAP treatments, showing that Setup C resulted in the highest fruit count. Neither Setup A nor Setup D produced any fruit.

In contrast, Setup B grew one more fruit throughout the study. This alignment reinforces that SAPs contribute to enhanced nutrient absorption and overall plant health, as reflected in their fruit yield.

Measuring the fruit yield of a plant is key to determining the successful growth of plants, especially in crops. The ability of a plant to absorb nutrients, its overall productivity, and its health are directly exemplified by its fruit production. The significant effectiveness of an agricultural treatment or practice can be reflected in the increase in the fruit yield of a plant (Singh & Kumar, 2020). Superabsorbent polymers exhibit a positive effect on tomato plants since there is an observed increase in their fruit yield after application (Cerasola et al., 2022). Accordingly, the different superabsorbent polymers in this study proved to be effective in increasing the fruit yield of the tomato plants. In particular, setup C with the combined shrimp and potato superabsorbent polymers produced the most yield with three fruits after the four-week observation.

Table 1.5 Summary of data on Plant Growth when Taken Collectively

	(Set up A)Shrimp Shell Wastes SAP	(Set up B)Potato Peels SAP	(Set up C)Shrimp Shell Wastes and Potato Peels SAP	(Set up D)Controlled Plant
Height difference	15 cm	8.0 cm	15 cm	3.3 cm
Average leaf count	435 pcs	109 pcs	522 pcs	365 pcs
Average flower count	5 pcs	2 pcs	15 pcs	0 pcs
Average fruit yield	0 fruits	2 fruits	3 fruits	0 fruits

Table 1.5 summarizes the results of the different growth factors observed from the tomato plants throughout their four-week observation period. The height difference was calculated by subtracting the measurement of week one from the height taken in week four. The greatest height difference was observed in setups A and C with shrimp SAP and mixed SAP, respectively. Meanwhile, the average leaf, flower, and fruit count was taken by adding all measurements and dividing them by the four-week time frame. The highest average leaf count was seen in setup C, having 522 leaves. The greatest leaf count was also observed in setup C with a 15-flower average. Lastly, the most fruits were recorded from setup C, with three fruits. The data revealed that Setup C consistently outperformed the other setups across all measured growth factors. Setup A also demonstrated a significant height difference but produced no fruits, suggesting that while vertical growth was promoted, reproductive development might have been limited. Setup B, despite a lower height gain, was able to produce fruits, indicating that height alone does not determine fruiting success. Setup D showed the least performance across all parameters, suggesting that the lack of treatment was less effective in promoting plant growth and fruiting.

Superabsorbent polymers are designed to increase absorption capacity and increase water retention because of their swelling properties (Batara et al, 2024). The production of such superabsorbent polymers is to address concerns surrounding water security and seek a non-harmful alternative to the current synthetic polymers. Chitin and chitosan were observed to have an encouraging effect on seed germination compared to untreated setups (Kanawi et al., 2021). Moreover, chitin is known to be an N-acetyl-D-glucosamine polymer that enhances plant growth and exhibits positive development in tomato plants (Egusa et al., 2020). Chitin increased soil nitrogen levels; however, plant growth promotion was still observed even under adequate nitrogen conditions, implying additional mechanisms beyond supplementing nutrients (Tender et al., 2024). Therefore, the growth of the tomato plants across various metrics may be attributed to the growth-promoting property of chitin.

Starch has been commonly incorporated into hydrogels and starch-based fertilizers, which emphasizes its quality and potential to optimize nutrients and promote plant growth (Salimi et al., 2023). The application of starch-based superabsorbent polymers was also noted to enable plants to receive and absorb water despite stressful conditions (Pacholczak et al., 2023). The properties of starch to enhance plant development also contribute to the efficacious effects of the SAP on the different factors. Combining both chitin and starch causes the benefits of each to manifest in the mixed SAP setup, which had the best overall result.

2. The effectiveness of different types of absorbent polymers compare in terms of their water absorption capacity and retention over time

Table 2.1*Comparison of Water Absorption of Various Superabsorbent Polymers (SAPs) by Computing Water Lost by Plants over 24 Hours*

	(Set up A)Shrimp Shell Wastes SAP	(Set up B)Potato Peels SAP	(Set up C)Shrimp Shell Wastes and Potato Peels SAP	(Set up D)Controlled Plant
Wet Weight				
Dry Weight				
Water Loss	0.3 kg	0.2 kg	0.3 kg	0.5 kg
Rank(in terms of water retention)	2	1	2	3

Table 2.1 showcases the water loss experienced by the plants with different superabsorbent polymers. The wet weight of the soil was recorded right after watering, and the dry weight was also recorded after 24 hours. To calculate the water loss, the dry weight was subtracted from the wet weight, and then ranked according to which had the least water loss. Setup B experienced the least water loss with 0.2 kg. Concurrently, Setup A and C witnessed a 0.3 kg water loss. Setup D faced the most water loss, with 0.5 kg, ranking third across all setups.

Both synthetic and natural superabsorbent polymers (SAPs) exhibit water absorption qualities that can be evaluated by their water intake capacity, retention, and release rates that lessen irrigation frequency (Kumar & Nair, 2017). The study highlighted that natural SAPs can perform similarly to synthetic polymers regarding their water retention capacities, significantly contributing to the development of agricultural practices targeting water management. In a study comparing the water retention capacity of natural superabsorbent polymer and a commercial polymer, both successfully increased water retention, but greater values were noted with the group treated with the organic SAP (Palma et al., 2024). Starch is a biopolymer with its two components named amylopectin and amylose, that are commonly used to form starch-based hydrogels (Dong et al., 2024). The soil water retention was increased when more amounts of amylopectin are present in a starch-based hydrogel due to its hydrophilic nature (Luo et al., 2021). Although all the plants treated with varying superabsorbent polymers displayed less water loss than those without SAPs, it is notable that setup B, containing potato SAP, showed the greatest water retention, as supported by the water absorption capacities of starch found in the potato peels used. Overall, this observation exemplifies that water retention is increased with organic superabsorbent polymers, as compared to no treatment at all.

Table 2.2*Comparison of Water Absorption of Various Superabsorbent Polymers (SAPs) usingA Commercial Soil Moisture Sensor*

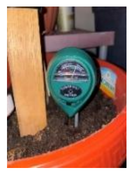
	(Set up A)Shrimp Shell Wastes SAP	**(Set up B)Potato Peels SAP**	**(Set up C)Shrimp Shell Wastes and Potato Peels SAP**	**(Set up D)Controlled Plant**
Photos				
% Soil moisture after watering	100%	100%	100%	100%
Photos				
%Soil moisture after 24 hours	60%	70%	80%	50%
Water Loss	40%	30%	20%	50%
Rank (in terms of water retention)	**3**	**2**	**1**	**4**

Table 2.2 depicts the various superabsorbent polymers' ability to retain moisture when applied to the plant. A commercial soil moisture sensor was used to measure the water retention in the soil of each setup on a scale of one to ten, which was then multiplied by ten to calculate the moisture percentage. The soil moisture percentage after 24 hours was subtracted from the measurement right after watering to compute the water loss experienced. The water retention was measured four weeks after the plant was treated with the various SAPs. Among the different setups, the mixed SAP plants experienced the least water losswith 20%, meaning the soil retained the most moisture after 24 hours. Meanwhile, the potato SAP observed a 30% water loss, keeping most of its water content. Moreover, the shrimp SAP lost 40% of its original moisture, ranking third among the setups. The least water retention was observed for the controlled plant because the setup lost 50% of water after one day.

Soil water moisture is a crucial factor in plant growth and ensures sustainability in long-term development. Superabsorbent polymers significantly enhance soil water retention, reduce water loss, and improve plant-available water capacity (Wang et al., 2023). Starch is a biomacromolecule polymerized of highly hydrophilic glucose, which is why it is generally used as a water-retaining agent (Chang et al., 2021). Chitin is an effective biopolymer that functions as an absorbent polymer that is able to soak up to 1500 gm of water in proportion to one gram of superabsorbent polymer applied (Sahoo, 2023). These polymers absorb and retain large amounts of water, which are gradually released into the soil, ensuring that plants have access to water even during dry periods. The ability to maintain moisture levels in the soil not only reduces the necessity for frequent irrigation but also minimizes water wastage through evaporation and runoff. As observed in the treated plants, superabsorbent polymers help maintain consistent soil moisture, which is essential for optimal root growth and nutrient uptake, best when shrimp SAP and potato SAP are combined.

3. Comparison of the effects of different superabsorbent polymers (SAPs) on the overall health and appearance of plants

Table 3 *Visual Assessment of Overall Health and Appearance of Tomato Plants Across Different Treatments*

	(Set up A)Shrimp Shell Wastes SAP	**(Set up B)Potato Peels SAP**	**(Set up C)Shrimp Shell Wastes and Potato Peels SAP**	**(Set up D)Controlled Plant**
Photo				
Leaf Color	Green	Green	Green	Yellowish
Leaf Texture	Smooth	Smooth	Smooth	Smooth
Leaf Shape and Structure	Round	Round	Round	Round
Leaf Size	Normal-sized	Normal-sized	Normal-sized	Shrunken
Stem Condition	Firm	Firm	Firm	Soft
Growth Uniformity	Even growth	Even growth	Even growth	Even growth

Table 3 lists the descriptions of each plant containing varying superabsorbent polymers when assessed on visual appearance. Using a comparative visual assessment for tomato plants, the setups were categorized based on which characteristics matched their descriptions. Setups A, B, and C exhibited healthy plant growth characteristics with a green leaf color, smooth leaves, regular leaf shapes, normal-sized leaves, firm stems, and even growth. Meanwhile, Setup D showed a smooth texture, regular-shaped leaves, and even growth, but it had yellowish and tinier leaves with a softer stem compared to the other setups.

Plant health can be evaluated qualitatively through visual inspection techniques and digital imaging technologies. Such visual indicators include leaf color, texture, and overall plant vigor that help identify abnormalities in the growth of a plant before manifesting into damages that affect any numerical measurements (Zhao & Liu, 2019). It was emphasized that inspecting the visual condition of plants, from their leaves to their external appearance, is key to assessing overall plant health in horticultural environments. The three setups containing the varying superabsorbent polymers all manifested features of a healthy plant. Hence, these attributes showcase the positive effect of natural SAPs on the appearance and health of the plant.

Green leaves in plants indicate that a plant is photosynthesizing effectively, which promotes strong growth and fruit production. Meanwhile, yellowish leaves indicate that the plant may be experiencing decreased chlorophyll content and photosynthesis failure (Cheng et al., 2022). Leaf yellowing can also be a result of a deficiency in some of the key nutrients, such as nitrogen, iron, and magnesium. (Shreevastav et al., 2021). This concept suggests that the green leaves present in setups A, B, and C prompt that the plants are healthy and are in a balanced environment, while the yellow leaves found in the control group signal stress, signifying that it is in an imbalanced condition.

Observing visual indicators is key for the interpretation of potential diseases in plant images (Khalid & Karan, 2024). For many plant species, smooth leaves are the typical and healthy state of their foliage. It indicates proper cell development and cuticle formation. It is essential to look at the overall appearance of the plant, including leaf texture, to get a comprehensive understanding of its health. Leaf morphology is linked to fruit quality since photosynthetic organs affect the fruit quality produced by a certain plant (Nakayama et al., 2023). Based on the identification of the leaf texture, the tomato plants all displayed smooth leaf textures, meaning the plants are in good condition.

Leaf size is another determinant of overall plant health since irregularities in growth hint to abnormalities within the plant. Infection in tomato plants is characterized by a yellowish and curly appearance, making its leaves appear shrunken (Cao et al., 2024). The change in leaf size demonstrates the photosynthetic capability of a plant, meaning manifestations are directly reflected when irregularities occur (Wang et al., 2025). The setups containing the various organics SAPs displayed normal-sized leaves, while the control plant presented shrunken leaves. It can be suggested that the untreated plant lacks the proper nutrient intake needed to maintain the regular leaf size of a tomato plant.

Rounder leaves in tomato plants significantly influence fruit yield and sugar content, greatly enhancing overall fruit quality. The leaf shape and leaf-vein density directly affect the availability of glucose(BRIX) in tomatoes, wherein rounded leaves pose a positive effect on both fruit sugar content and an increase in fruit yield (Rowland et al., 2020). As photosynthesis occurs in leaves, they must efficiently absorb light energy, facilitate the gas exchange, and maintain optimal temperature and water levels for the process to transpire effectively.Additionally, rounder leaves possess a larger surface area exposed to sunlight, allowing them to absorb more light than narrower or curled leaves, thereby enhancing photosynthetic efficiency (Tsukaya, 2018). Accordingly, all the tomato plants displayed rounded leaves, indicating that the plants are able to produce food systematically.

The stem plays a crucial role in plant survival by supporting its structure and serving as a transport system for essential materials. The stem balances the demand of water transport, mechanical transport, and storage through specialized structures (Olson et al., 2021). Firm stems in tomato plants are a strong indicator of healthy vascular development, proper water transport, and structural integrity (Lee et al., 2019; Qaderi et al., 2019). Soft stems in tomato plants are often indicative of infections by pathogens such as Fusarium oxysporum and Pectobacteriumcarotovorum. These pathogens compromise the vascular system and structural integrity of a plant, which leads to wilting, stem softening, and potential plant collapse (Bartz et al., 2019; Lee et al., 2022). Hence, it can be established that the firm stems found from setups A to C are caused by the application of SAP, while the soft stem present in the control group suggests the likelihood of future plant health decline.

Plant growth analysis is a method used to understand how plants respond to specific environmental conditions.Even growth in tomato plants indicates that tomato plants should receive adequate nutrients the plant needs to grow, such as soil, water, sunlight, and are not suffering from environmental stressors or diseases; otherwise, mineral deficiencies affect metabolism, often leading to changes in plant structure (Maia, 2019). Additionally, it ensures that every fruit ripens at around the same time, producing a steady and consistent harvest by enabling the plant to generate an abundance of flowers and fruits. The even growth seen in all setups indicates that the tomato plant grew uniformly.

Discussion:-

The plants treated with the superabsorbent polymers (SAPs) revealed better results than the control group without the SAP. Superabsorbent polymers in plant cultivation significantly promote positive growth in plant height, leaf count, flower development, and fruit yield of the plants by absorbing and retaining water within their network structure (Benard et al., 2021). Organic SAPs increase the ability of soil to hold water, which makes soil moisture more available for plants and advancing growth among plant organs. Overall, the setup C presented the most effective result since it displayed rapid growth in plant height, leaf count, and flower development. Additionally, it had the most fruit yield, showing that it is ideal in improving agricultural productivity. This implies that both chitin and starch simultaneously help in plant growth while acting as superabsorbent polymers as well.

The study underscores the role of superabsorbent polymers (SAPs) in enhancing soil moisture retention by assessing their absorption over 24 hours. The findings show that SAPs enhance water retention and maintenance of water moisture within the soil, ensuring that water is available for the plants to develop normally. Furthermore, the set-ups containing the organic superabsorbent polymers were observed to be effective in achieving such qualities. These findings align with prior studies highlighting how natural SAPs are promising soil amendments for enhancing water retention, optimizing plant growth, and increasing crop yield in sustainable farming practices (Negim et al., 2024).

The tomato plants treated with shrimp SAP, potato SAP, and mixed SAP appeared to have thriving overall plant health under several visual cues. The effectiveness of the superabsorbent polymers was observed from the better leaf color, texture, shape, size, and stronger stems of treated plants compared to the control plant, which had yellowish, smaller leaves and softer stems. In line with the study of Yang et al. (2019), superabsorbent polymers have been used as water-saving materials and soil conditioners. With this, the water retention of the soil was enhanced because of the SAP, which supports the growth of the overall health of the plants, helping them develop healthily.

The observation period only transpired for four weeks and was only tested on tomato plants, meaning more manifestations may still occur over time and affect other plant types differently. Moreover, more advanced scientific equipment may be used for increased accuracy in measuring the effects of the superabsorbent polymers on the soil's composition. Since the quantity of materials was made for a small-scale examination, further proportions may be scaled up to determine the proper calculations for mass production.

Conclusion:-

In conclusion, this study underlines the efficacy of using various superabsorbent polymers using shrimp *(Caridea)* shell waste and potato *(Solanum tuberosum)* peels in improving water retention, enhancing growth, and maintaining the overall health of a plant. The superabsorbent polymers were revealed to have water-retaining properties by successfully reducing water loss and sustaining the water moisture found in the soil. By comparing the different SAPs with one another, the set-up containing the combined shrimp and potato SAP delivered the best results with progressing height, fruit yield, leaf count, flower count, and healthy appearance. The outcome highlights the properties of chitin from shrimp shell wastes and starch from potato as effective organic superabsorbent polymers for stimulating tomato plant development and enhancing water retention that can be applied in future agricultural practices, particularly aiding regions with water scarcity or irregular rainfall patterns.

For further studies, the researchers recommend including the plant weight in measuring the overall plant growth to measure biomass without the water content affecting its value precisely. This improvement will also allow the monitoring of root development within the plant to analyze water and nutrient absorption further. Moreover, the researchers advise observing the effects of varying the ratio of the mixed superabsorbent polymer to determine if it has any significant impact. It is highly emphasized that all plant setups be cultivated under the same conditions since factors such as the state of the environment can directly impact the growth and consistency of the plant. Applying these modifications would further contribute to formulating superabsorbent polymers that are effective yet cost-efficient for different sectors.

References:-

1. Abdelgalil, S. A., & Abo-Zaid, G. A. (2022). Bioprocess development as a sustainable platform for eco-friendly alkaline phosphatase production: an approach towards crab shells waste management. *MicrobCell Fact, 21*, 141. https://doi.org/10.1186/s12934-022-01868-4
2. Bachra, Y., Damiri, F., Berrada, M., Tuteja, J., Sand, A. (2023). Introduction of Superabsorbent Polymers. *Properties and Applications of Superabsorbent Polymers.*https://doi.org/10.1007/978-981-99-1102-8_1
3. Bartz, J. A., Mahovic, M. J., &Tenney, J. D. (2019). Susceptibility of lenticels within the stem depression of tomato fruit to bacterial soft rot. *Plant Disease, 103*(5), 1101–1106. https://doi.org/10.1094/PDIS-02-16-0173-RE
4. Batara, B., Steven, S., Mulyana, M., & et al. (2024). Recent Advances, Applications, and Challenges in Superabsorbent Polymers to Support Water Sustainability. *Journal of Applied Polymer Science, 142*(11). https://doi.org/10.1002/app.56588
5. Cao, X., Huang, M., Wang, S., Li, T., Huang, Y. (2024). Tomato yellow leaf curl virus: Characteristics, influence, and regulation mechanism. *Plant Physiology and Biochemistry, 213*. https://doi.org/10.1016/j.plaphy.2024.108812
6. Cerasola, V. A., Perlotti, L., Pennisi, G., Orsini, F., &Gianquinto, G. (2022). Potential Use of Superabsorbent Polymer on Drought-Stressed Processing Tomato (*Solanum lycopersicum* L.) in a Mediterranean Climate. *Horticulturae, 8(*8), 718. https://doi.org/10.3390/horticulturae8080718
7. Casadidio C, Peregrina DV, Gigliobianco MR, Deng S, Censi R, Di Martino P. (2019). Chitin and Chitosans: Characteristics, Eco-Friendly Processes, and Applications in Cosmetic Science. *Mar Drugs. 17*(6):369. doi: 10.3390/md17060369.
8. Chang, L., Xu, L., Liu, Y., & Qui, D. (2021). Superabsorbent polymers used for agricultural water retention. *Polymer Testing, 94,* 107021. https://doi.org/10.1016/j.polymertesting.2020.107021.
9. Chen, J., Wu, J., Raffa, P., Picchioni, F., & Koning, C. E. (2022). Superabsorbent Polymers: From long-established, microplastics generating systems, to sustainable, biodegradable and future proof alternatives. *Progress in Polymer Science, 125,* 101475. https://doi.org/10.1016/j.progpolymsci.2021.101475
10. Cheng, M., Meng, F., Mo, F., Chen, X., Zhang, H., & Wang, A. (2022). Insights into the molecular basis of a yellow leaf color mutant (*ym*) in tomato (*Solanum lycopersicum*). *Scientia Horticulturae, 125*, 110743. https://doi.org/10.1016/j.scienta.2021.110743
11. Coviello, T., Matricardi, P., Marianecci, C., &Alhaique, F. (2007). Polysaccharide hydrogels for modified release formulations. *Journal of Controlled Release, 119*(1), 5–24. https://doi.org/10.1016/j.jconrel.2007.01.004
12. Dehkordi, D. (2016). The Effects of Superabsorbent Polymers on Soils and Plants. *Pertanika Journals Tropical*

Agricultural Science, 39(3), 267–298. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20163254972

13. Dong, Y., Ghasemzadeh, M., Khorsandi, Z., Sheibani, R., &Nasrollahzadeh, M. (2024). Starch-based hydrogels for environmental applications: A review. *International Journal of Biological Macromolecules, 269*(2), 131956. https://doi.org/10.1016/j.ijbiomac.2024.131956.

14. Egusa, M., Matsukawa, S., Miura, C., Nakatani, S., Yamada, J., Endo, T., Ifuku, S., &Kaminaka, H. (2020). Improving nitrogen uptake efficiency by chitin nanofiber promotes growth in tomato. *International journal of biological macromolecules, 151*, 1322–1331. https://doi.org/10.1016/j.ijbiomac.2019.10.178

15. Gómez-Estaca, J., Tovar, C., Montero, P., & Gómez-Guillén, M. (2023). StrGuctural, viscoelastic, and emulsifying properties of shrimp chitin nanowhisker dispersions as a function of acidic pHs. *Journal of Food Engineering, 351*, 111519. https://doi.org/10.1016/j.jfoodeng.2023.111519

16. Hossain, M. D., & Ali, M. H. (2017). Leaf count as a key indicator of plant health and growth in horticultural crops. *Journal of Plant Growth Regulation, 36*(4), 922-933. https://doi.org/10.1007/s00344-017-9734-1

17. Kanawi, M., Haydar, M., & Radhi, W. (2021). Effect of Chitin and Chitosan in Improvement of Plant Growth and Anti-Fungal Activity. *Egyptian Journal of Botany, 61*(2), 513-519. doi: 10.21608/ejbo.2021.41084.1549

18. Kandar, C. C., Hasnain, M. S., & Nayak, A. K., (2021). Chapter 1 - Natural polymers as useful pharmaceutical excipients. *Academic Press*, 1-44. https://doi.org/10.1016/B978-0-12-820043-8.00012-8

19. Kathi, S., Simpson, C., Umphres, A., & Schuster, G. (2021). Cornstarch-based, Biodegradable Superabsorbent Polymer to Improve Water Retention, Reduce Nitrate Leaching, and Result in Improved Tomato Growth and Development. *American Society for Horticultural Science. 56*(12), 1486-1493. https://doi.org/10.21273/HORTSCI16089-21

20. Khalid, M. M., &Karan , O. (2023). Deep Learning for Plant Disease Detection. *International Journal of Mathematics, Statistics, and Computer Science, 2*, 75–84. https://doi.org/10.59543/ijmscs.v2i.8343

21. Krasnopeeva, E. L., Panova, G. G., &Yakimansky, A. V. (2022). Agricultural Applications of Superabsorbent Polymer Hydrogels. *International Journal of Molecular Sciences, 23*(23), 15134. https://doi.org/10.3390/ijms232315134

22. Kumar, S., & Nair, S. S. (2017). Comparative study of water absorption properties of various superabsorbent polymers and their application in soil moisture retention. *Journal of Applied Polymer Science, 134*(5), 45113. https:doi.//org/10.1002/app.45113

23. Lee, J., Han, S., Lee, H. Y., et al. (2019). Brassinosteroids facilitate xylem differentiation and wood formation in tomato. *Planta*, 249, 1391–1403. https://doi.org/10.1007/s00425-019-03094-6

24. Lee, Y. G., Jeong, H. J., Choi, J. W., & Myung, H. (2022). Development of a bacteriophage cocktail against Pectobacteriumcarotovorum subsp. carotovorum for the control of soft rot disease. *Microorganisms, 10*(10), 2013. https://doi.org/10.3390/microorganisms10102013

25. Li, K., Xing, R., Liu, S., & Li, P. (2020). Chitin and Chitosan Fragments Responsible for Plant Elicitor and Growth Stimulator. *Journal of Agricultural and Food Chemistry, 68*, 12203-12211. https://doi.org/10.1021/acs.jafc.0c05316

26. Liu, J., & Chen, L. (2018). Plant height as an important indicator of growth success in agricultural crops. *Field Crops Research, 223*, 84-92. https://doi.org/10.1016/j.fcr.2018.04.006

27. Maghsoudi, S., TaghaviShahraki, B., Rabiee N., Fatahi, Y., Dinarvand, R., Tavakolizadeh, M., Ahmadi, S., Rabiee, M., Bagherzadeh, M., Pourjavadi, A., Farhadnejad, H., Tahriri, M., Webster, T. J., & Tayebi, L. (2020). Burgeoning Polymer Nano Blends for Improved Controlled Drug Release: A Review. *International Journal of Nanomedicine, 15*, 4363–4392. http://dx.doi.org/10.2147/IJN.S252237

28. Maia, J., Martinez, H., Clemente, J., Ventrella, M., &Milagres, C. (2019). Growth, nutrient concentration, nutrient accumulation and visual symptoms of nutrient deficiencies in cherry tomato plants. *Semina: CiênciasAgrárias,*

Londrina. *40*, 585-598. https://doi.org/10.5433/1679-0359.2019v40n2p585

29. Malik, S., Chaudhary, K., Malik, A., Punia, H., Sewhag, M., Berkesia, N., Nagora, M., Kalia, S., Malik, K., Kumar, D., Kumar, P., Kamboj, E., Ahlawat, V., Kumar, A., & Boora, K. (2022). Superabsorbent Polymers as a Soil Amendment for Increasing Agriculture Production with Reducing Water Losses under Water Stress Condition. *Polymers*, *15*(1), 161. https://doi.org/10.3390/polym15010161

30. Maschmeyer, T., Luque, R., & Selva, M. (2020). Upgrading of marine (fish and crustaceans) biowaste for high added-value molecules and bio(nano)-materials. *Chemical Society Reviews, 49*(13), 4527–4563. https://doi.org/10.1039/c9cs00653b

31. Negim, O., Moharam, M., Elsayed, E., & Thabit, F. (2024). The Combination between Super Absorbent Polymers (SAPs) and Biofertilizers could be an Ecofriendly Approach for Soil Chemical Properties improving and Sustainable Wheat (Triticum sativum) Production in Sandy Loam Soil. *Journal of Soil Science and Plant Nutrition*, *24*(3), 4349–4365. https://doi.org/10.1007/s42729-024-01839-1

32. Oladosu, Y., Rafii, M. Y., Arolu, F., Chukwu, S. C., Salisu, M. A., Fagbohun, I. K., Muftaudeen, T. K., Swaray, S., &Haliru, B. S. (2022). Superabsorbent Polymer Hydrogels for Sustainable Agriculture: A review. *Horticulturae, 8*(7), 605. https://doi.org/10.3390/horticulturae8070605

33. Olson, M. E., Anfodillo, T., Rosell, J. A., Petit, G., Crivellaro, A., Isnard, S., ... & León-Gómez, C. (2021). Trade-offs among transport, support, and storage in xylem of angiosperm trees. *Proceedings of the National Academy of Sciences, 118*(36), e2104336118. https://doi.org/10.1073/pnas.2104336118

34. Ostrand, M. S., DeSutter, T. M., Daigh, A. L. M., Limb, R. F., Steele, D. D. (2020). Superabsorbent polymer characteristics, properties and applications. *AgrosystGeosci Environ*, *3*(1). https://doi.org/10.1002/agg2.20074

35. Pacholczak, A., Nowakowska, K., &Monder, M. (2023). Starch-Based Superabsorbent Enhances the Growth and Physiological Traits of Ornamental Shrubs. *Agriculture*, *13*(10), 1893. https://doi.org/10.3390/agriculture13101893

36. Palma, D., Lagos, O., Souto, C., Pérez, A., Quezada, L., Hirzel, J., Vera, M., Ulloa, J., &Urbano, B. (2024). Evaluation of a Natural Superabsorbent Polymer on Water Retention Capacity in Coarse-Textured Soils. *Water*, *16*(22), 3186. https://doi.org/10.3390/w16223186

37. Qaderi, M. M., Martel, A. B., & Dixon, S. L. (2019). Environmental factors influence plant vascular system and water regulation. *Plants, 8*(3), 65. https://doi.org/10.3390/plants8030065

38. Rajeswari, S., Prasanthi, T., Malli, R. (2017). Natural Polymers: A Recent Review. *World Journal of Pharmacy and Pharmaceutical Sciences, 6,* 472–494. https://doi.org/10.20959/wjpps20178-9762

39. Rappoport, G. (2024, January 10). *Creating an Inexpensive, Effective Super Saturated Polymer Out of Citrus Polysaccharides*. https://doi.org/10.21203/rs.3.rs-3846504/v1

40. Rowland, S., Zumstein, K., Nakayama, H., Cheng, Z., Flores, A., Chitwood, D., Maloof, J., & Sinha, N. (2020). Leaf shape is a predictor of fruit quality and cultivar performance in tomato. *New Phytologist, 3,* 226. https://doi.org/10.1111/nph.16403

41. Sahoo, S. (2023). Chitin/Chitosan Based Superabsorbent Polymers. In: Pradhan, S., Mohanty, S. (eds) Bio- based Superabsorbents. *Engineering Materials*.https://doi.org/10.1007/978-981-99-3094-4_5

42. Salimi, M., Channab, B., Idrissi, A., Zahouily, M., &Motamedi, E. (2023). A comprehensive review on starch: Structure, modification, and applications in slow/controlled-release fertilizers in agriculture. *Carbohydrate Polymers, 322,* 121326. https://doi.org/10.1016/j.carbpol.2023.121326.

43. Schmidt, B. &Wilpiszewsla, K. (2024). The effect of cross-linking agent amount and type on the sorption properties of starch graft polyacrylamide and poly(acrylic acid) copolymers. *Polish Journal of Chemical Technology*, *26*(4), 81-86. https://doi.org/10.2478/pjct-2024-0043

44. Seven, S., Menceloğlu, Y., Ünlü, K., Kahraman, K., et al. (2024). Investigation of the effect of superabsorbent polymer application on soil moisture and plant growth. *Frontiers in Life Sciences and Related Technologies, 5*(1), 24-30. https://doi.org/10.51753/flsrt.1348591

45. Shamsina, J., Oldham, T., & Rogers, R. (2019). Applications of Chitin in Agriculture. *Sustainable Agriculture Reviews, 36,* 125-146. https://doi.org/10.1007/978-3-030-16581-9_4

46. Sharma, S., & Gupta, A. (2019). The significance of flower development in assessing plant growth and reproductive success. *Plant Reproduction, 32*(1), 1–12. https://doi.org/10.1007/s00497-019-00347-2

47. Shreevastav, C. K., Subedi, S., Gajurel, S., & Basnet, P. (2022). A review on nutrient deficiency symptoms and effects on tomato plants. *Food and Agri Economics Review*, 2(1), 34–36. http://doi.org/10.26480/faer.01.2022.34.36

48. Shome, R., &Tupe, Rashmi. (2018). Organic Super Absorbent Polymers (SOP). https://doi.org/10.13140/RG.2.2.21077.45280

49. Singh, A. (2021). An Introduction to Experimental and Exploratory Research. *SSRN*. https://doi.org/10.2139/ssrn.3789360

50. Singh, R., & Kumar, S. (2020). Role of fruit yield as a measure of plant growth success in agricultural crops. *Agricultural Systems, 175*, 102615. https://doi.org/10.1016/j.agsy.2019.102615

51. Singh, R., Shitiz, K., & Singh, A. (2017). Chitin and chitosan: biopolymers for wound management. *International Wound Journal, 14*(6), 1276–1289. https://doi.org/10.1111/iwj.12797

52. Srivastava, P., & Kalam, S. (2019). Natural Polymers as Potential Antiaging Constituents. *IntechOpen*. https://doi.org/10.5772/intechopen.80808

53. Sudhakar, K., Amalraj, L., Tejaswini, V. L., Sree, N. M., Harshitha, P. D., Julie, M. R. (2021). Eco-friendly Biodegradable Super Absorbent Polymers (SAPs); An Effective Water Retainer and Agrofertilizer. *Alinteri Journal of Agriculture Sciences, 36*(1), 753. https://doi.org/10.47059/alinteri/V36I1/AJAS21105

54. Supare, K., &Mahanwar, P. A. (2022). Starch-derived superabsorbent polymers in agriculture applications: an overview. *Polymer Bulletin,79*, 5795–5824. https://doi.org/10.1007/s00289-021-03842-3

55. Tariq, Z., Iqbal, D. N., Rizwan, M., Ahmad, M., Faheem, M., & Ahmed, M. (2023). Significance of biopolymer-based hydrogels and their applications in agriculture: a review in perspective of synthesis and their degree of swelling for water holding. *RSC Advances, 13*(35), 24731–24754. https://doi.org/10.1039/d3ra03472k

56. Tender, C., Vandecasteele, M., Ommeslag, S., Zutter, N., et al. (2024). *Linnemannia elongata:* A Key Species in Chitin-Based Plant Growth Promotion. *Phytobiomes, 8*(3), 2471-2906. https://doi.org/10.1094/PBIOMES-05- 23-0031-R

57. Tsukaya, H. (2018, July). Leaf shape diversity with an emphasis on leaf contour variation, developmental background, and adaptation. *Seminars in Cell & Developmental Biology. 79*, 48-57. https://doi.org/10.1016/j.semcdb.2017.11.035

58. Wang, X., Wang, Y., Zheng, Z., & Cui, Y. (2025). GPA1 is a determinant of leaf width and fruit size in tomato. *Plant Science, 352*. https://doi.org/10.1016/j.plantsci.2024.112336

59. Wang, Y., Zhang, X., Li, J., & Chen, L. (2023). Superabsorbent polymers as a soil amendment for increasing soil water holding capacity: A review. *Polymers, 15*(1), 161. https://doi.org/10.3390/polym15010161

60. Wani, A. K., Akhtar, N., Mir, T., Rahayu, F., Suhara, C., Anjli, A. Chopra, C., Singh, R., Prakash, A., El Messaoudi, N., Fernandes, C. D., Ferreira, L. F. R., Rather, R. A., &Américo-Pinheiro, J. H. P. (2023). Eco-friendly and safe alternatives for the valorization of shrimp farming waste. *Environmental Science and Pollution Research.* https://doi.org/10.1007/s11356-023-27819-z

61. Whang, M., Yu, H., & Kim, J. (2021). Superabsorbent Polymer Network Degradable by a Human Urinary

Enzyme. *Polymers, 13*. https://doi.org/10.3390/polym13060929

62. Yang, H., Gözaydın, G., Nasaruddin, R. R., Har, J. R. G., Chen, X., Wang, X., & Yan, N. (2019). Toward the Shell Biorefinery: Processing Crustacean Shell Waste Using Hot and Carbonic Acid. *ACS Sustainable Chemistry & Engineering, 7*(5), 5532-5542. https://doi.org/10.1021/acssuschemeng.8b06853

63. Yan, B., Yang, H., Zhang, N., Cheng, J., Huang, J., Zhao, J., Zhang, H., Chen, W., & Fan, D. (2023). Microwave-assisted depolymerization of chitin and chitosan extracted from crayfish shell waste: A sustainable approach based on graphene oxide catalysis. *International Journal of Biological Macromolecules, 251,* 126296. https://doi.org/10.1016/j.ijbiomac.2023.126296

64. Zhao, F., & Liu, Y. (2019). Qualitative evaluation of plant health using visual inspection and digital imaging technologies. *Environmental Monitoring and Assessment, 191*(5), 309. https://doi.org/10.1007/s10661-019-7381-3

65. Zubair, A. (2023). Experimental Research Design-types & process. *Academia Open.* https://www.researchgate.net/publication/367044021_Experimental_Research_Design-types_process