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Exploring the Potential of Biodegradable Superabsorbent Hydrogel as a Sustainable Solution for Water Management in Agriculture

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Abstract

Superabsorbent hydrogels are a kind of gel that is formed by chemically stabilizing a tridimensional network of polymers with hydrophilic properties. Hydrogels are commonly researched and advocated for agricultural purposes during the past 40 years to improve water supply for plants by boosting the water-retaining qualities of growing media (substrates with or without soil). The bulk of commonly accessible commercially available hydrogels are acrylate-based. Hence not biodegradable. Because of the increased focus on environmental problems, biodegradable hydrogels are gaining popularity for possible commercial applications in agriculture. In this piece, we assessed a new kind of superabsorbent hydrogel based on cellulose for agricultural usage that is completely biodegradable and biocompatible. The tests aimed to validate the hydrogel's capacity to change the ability of the medium for development to retain water (substrates with and without soil). The hydrogel contains an influence on soil retaining water qualities. When compared to untreated soil, soil moisture increased by up to 400% at field capacity, as well as below the wilting point (-15 bar) compared to the field capacity of unaffected soil. Whenever perlite was treated with 1 or 2% (w/w) hydrogel, poor water holding soilless substrate capability, container capacity improved by 28 and forty-eight percent, correspondingly, with no decrease in air capacity. The hydrogel material tested positive for phytotoxicity, and cultivation studies with cucumber (on soil) and sweet leaves (without soil) demonstrated an improvement in the addition of hydrogel to the growing medium increased the plant's health and growth. The examined hydrogel proved to be appropriate for prospective agricultural applications. Its use deserves to be investigated further from a cost-effective approach.

Keywords: Sago starch (SS), polypropylene (PP), thermal properties, biodegradability, mechanical properties (MP), and thermo gravimetric analysis (TGA)

Full length article **Corresponding Author*, e-mail:*hodbiotech@iimtindia.net*

1. Introduction

The agricultural sector, along with the food business, is now dealing with several difficulties, the most serious of which are those induced by climate change, which is causing huge losses in crop yields, with drought harming among the key results of this approach [1].As a consequence, agriculture output is increasing conducted on dry as well as semi-arid soil wide pores, which results in reduced water and fertilizer retention, decreasing soil quality and productivity [2].These developing concerns drive the creation of novel, environmentally friendly, and highly efficient agricultural technology that reduce environmental effect while providing appropriate growth ecology for various plant species. Agriculture that is environmentally friendly and long-term necessitates a broader application of biology interactions a more natural logical utilization of only natural materials resources and manufacturing processes, as well as the usage of ecologically friendly materials technology to reduce pollution and boost soil fertility [3].Simultaneously, as a substitute for intense commercial farming, Organic agriculture is founded on a certain agricultural method framework that is created and controlled in three different ways: ecologically, economically, and socially. Plant production is guided by ecological principles, which include diversity, stability, equality, and productivity, and traditional technical aspects are being replaced with ecological ones. In this case, the most recent advancements in this subject are focused on discovering innovative as well as long-term solutions capable of responding to these aspects: ensuring water with little negative influence on the soil-plant system [4].Hydrogels were defined in a variety of ways, with the most specific definition referring to them as water-swelling substances with polymeric chains that have been cross-linked. Additionally, materials with extraordinary expanding capacity that does not need structural changes or changes in form and volume may be described. Integrate significant volumes containing water or watery solutions [5].In general, hydrophilic polymer networks in three dimensions could absorb at least 20% of their entire weight in water, and if the amount of water absorbs more than 95% of their hydrogen's total weight is referred to be super absorbent. The nature of hydrogels determines their structure and characteristics, which may be manufactured (non-biodegradable) like polyesters or natural (based on polysaccharides like agarose and alginate or proteins like gelatin or collagen), as well as the kind of links that exist between the macromolecular chains, that may be chemical or physical [6].Three-dimensional systems are physical gels that are connected via secondary connections, non-covalent linkages, hydrogen bonding, and electrostatic interaction), to form physical cross-linking connections between linear molecules [7]. These hydrogels' sol-gel look is they are helpful for biological applications since they are typically reversible and don't require chemical reactions. The most essential attribute of hydrogel is that they expand when there is water present and contract when there is none. The kind of polymer chain and the density of cross-linking influence the amount of swelling. The greater the water content, hydrogels can mimic genuine tissues thanks to improved mechanical in nature, diffusion, and adsorption properties. Furthermore, the higher the water concentration, the more bimolecular are linked to the surface, influencing the interactions between the hydrogel and biopolymer [8].The research [9] looked at the ability to synthesize carboxymethyl cellulose for the production of a highly absorbent hydrogel that may be employed in agriculture. A short overview of the literature is offered to assist investigators to obtain carboxymethyl cotton, which is produced by the carboxymethylation of recyclables. The research [10] evaluated and characterizes biodegradable hydrogels made from carboxymethylcellulose sodium salt (CMCNa) and hydroxyethyl cellulose (HEC) utilizing citric acid (CA) as a cross-linker. Infrared spectroscopy using the Fourier transform is employed to do chemical analysis on manufactured hydrogels. The research [11] highlighted the differences in the impact of SAH application in various textured soil, the presence of salt, and the SAH biodegradation in the environment. The study [12] standardized the procedure for preparing hydrogel-biochar composites using locally accessible Pine resin and biochar made from weed biomass, followed by specific features, as well as lastly, assessment as a controlled release fertilizer of mineral nutrient-impregnated biochar-hydrogel combination. The feature has resulted in various practical uses of these novel materials, notably in agriculture for enhancing soil water retention and plant water delivery. A brief overview of hydrogel uses in agriculture [13].The article [14] provided a summary of recent and current research on pill distribution one cellulose-based hydrogel's biological uses, tissue engineering and wound healing, healthcare, and sanitary goods, Smart materials are used for agricultural, textile, and industrial uses.The study [15] examined the popular recent advances in hydrophilic synthesis and bridging technologies, as well as hydrogel properties, covered, hydrophilic absorbent and releasing methods, hydrogel benefits and limits, and present and prospective urban applications farming. The article [16] concentrated on the manufacture of biodegradable and hydrogels made from cellulose that are biocompatible employing various techniques dependent on the crosslinking agents and cellulose dissolving solvents utilized. An investigation of the categorization of various forms of hydrogels was also presented. The article [17] created superabsorbent hydrogels obtained from agricultural waste that supports the sustainability of the environment and a circular economy in agriculture. The work [18] described the production of a hydrogel from a hitherto unknown Jhingan gum using a microwave-assisted approach for the efficient removal of hazardous substances RBBR dye derived from a water-based solution. Various analytical methods were used to validate the hydrogel that was created.Due to their high mineral and water retention, and release capability, smart polymeric and biopolymer materials may aid the agricultural industry. Researchers are presently developing and researching many forms of hydrogel as long-lasting and environmentally beneficial biopolymer agriculture materials.

2. Material and Methods

The cellulose-based sustainable superabsorbent polymer research method was given by the ColGel project. In summary, super absorbent hydrogels were created by combining two albumin derivatives, sodium carboxymethylcellulose (CMCNa) and hydroxyethylcellulose (HEC), citric acid (CA), and a polymer called chitosan. A substance that links together that can overcome. In a heat-activated approach, the cytotoxicity and related costs of different cross-linking agents were investigated. Details about the distinctive characteristics of hydro gel's component qualities.

2.1 The impact of a polymer on a sandy soil's liquid Discharge slope

The study was to determine how the addition of a polymer changed the liquid water-giving curve of sand. The soil utilized was a standard sandy soil from a farming region in Apulia noted for producing a lot of vegetables. Using Richard's pressure plate approach, moisture release curves of soil treated when the polymer fraction increases were generated. Five soil water potential values were tested, and soil moisture was estimated gravimetrically using the equation below for each potential value.

$$GWC(\%) = ((U_u - U_c)/U_c) * 100 \quad (1)$$

Where GWC = the gravimetric method amount of water in terms of dry weight;

U_u= Soil sample wet weight at a certain potential worth of water;

U_c = dry weight of the soil samples (105 °C).

2.2 Hydrogel's impact on the hydrology and physical Qualities of the material

The research study was to find out how the water-soluble gel affected some of the most significant economic and environmental features of perlite from an environmental vantage point. This substance, which has a high porosity but a small capacity for retaining water, was chosen as one of the most popular often utilized components in the manufacture of soilless growth medium. The test used a quick approach for assessing the physical parameters of an undisturbed substrate. Each perlite and hydrogel combination was tested in three pots. In a nutshell, the substrate-filled pots were placed in and immersed in a tank up to the soil's surface in water. Pots were immersed for 24 hours before undergoing three submersion (30-minute) and run-off (60-minute) cycles. Before removing the submerged pots from the tank, the openings on their bottoms were plugged. We determined the saturated substrate weight (U_u). The water level was recorded after the drainage holes were unplugged (X_2). The pots were then placed in a 105 °C oven until they acquired a constant weight, at which point the substrate's dry weight (U_c) was determined.

$$BD(g.cm^3) = U_c/X_1 \quad (2)$$

$$WCC(\%volume) = ((U_u - U_c)/X_1) * 100 \quad (3)$$

$$H_{index} = ((H/H_0)(K/K_0)) * 100 \quad (4)$$

$$TP(\%volume) = AFP + WCC \quad (5)$$

ANOVA was performed on the results for a randomized design using the conventional linear equation approach, and the LSD test was used to determine scores, P 0.05 being regarded as significant.

2.3Hydrogel's effects on plant growth

To assess the hydrogel's toxicity, a poisons test, as well as two culture experiments, were carried out, as well as the influence of a culturing medium modified with hydrogel on the development of plants and physiological indicators. Cucumbers alyssum and Centauries were evaluated for harmful effects on Petri plates. Glasses were then filled with 10 mL of water that was distilled and saturated hydrogel. Dishes were put in a dark growth environment at 25 degrees Celsius for 72 hours. Every therapy of a single species used six copies (dishes). The germination rate was computed using a specific equation: (Gindex).

$$H_{index} = ((H/H_0)(K/K_0)) * 100 \quad (6)$$

L and G = number of stones that grew and the duration of the root in the state of hydrogel;

L0and G0 = number of seeds that germinate and the length of the root under manage circumstances

2.4 Trials of Farming

Sandy soil treated with or without hydrogel was placed in plastic pots (9 L capacity). The pot was placed on elevated trough benches off the outside. Fertigation occurred. Administered using a timed drip irrigation method. The irrigation schedule was changed such that each irrigation restored the substrates to their maximum water-holding capacity. Cucumber seedlings were transplanted and nurtured in line with local agricultural techniques at the third true leaf stage.

There were a total of four in the trial: NO-HYDROGEL; HYDROGEL; NO-HYDROGEL-STRESS and HYDROGEL-STRESS then utilized for measurements, with the explicit purpose of evaluating the effect of gelatin on plants under water stress may be managed. A random block layout was used, with three replications per environment and five specimens in each repeat. Plant height, the highest material that is new, and the surface area of leaves are all important considerations that were measured on 35 DAT. The water condition of the facility was evaluated by measuring leaf dry matter proportion, the water potential, osmotic potential, as well as momentum propensity of plants from regulated water stress treatments.

The data went through a one-way transformation evaluation of variance (ANOVA) using the generic linear modeling technique and means were split using the P 0.05 is considered statistically significant for the LSD test.

$$H_{index} = ((H/H_0)(K/K_0)) * 100 \quad (6)$$

Pots made of plastic Perlite were used to fill seedling pots before they were put in the greenhouses on the ebb-and-flow bench. Water was mechanically over-irrigated into the pots until the first actual leaf developed, and then a complete nutrient solution (NS) was sub-irrigated. The use of irrigation frequency varied every day, between three and nine fustigations are performed, depending on the crop's growth stage. Substrates had the opportunity to absorb the NS for fifteen minutes before being extracted and reused for subsequent irrigations during each sub-irrigation session.

A growth study was done to measure the entire new mass of vegetation 46 to 63 days following planting (DAS), with the latter reflecting the conclusion throughout the crop cycle. The experimental setup was randomized; with seven repetitions each series included seven pots (subsamples) per intervention.

The data exposed to a single-way examination ANOVA utilizing a universal linear model modeling technique means were differentiated using the LSD test, with "P 0.05" being a significant difference.

3. Results and discussions

3.1. The impact of a polymer on the sandy soil's liquid Discharge slope

The addition in the sandy terrain of the region changed the soil's water retention capacity considerably (Fig. 1). The lowest hydro gel dosage almost quadrupled the moisture level of the unmodified soil at suction stress, while the greatest hydrogel dose approached 50% much greater as opposed to clay soil with strong structure and large water retention ability. Previous research found that adding conventional hydrophilic polymers to sandy ground increased its water retention capacity to levels equivalent to soils that are silty clay or loam.

When contrasted to the placebo group, moisture percentage rose by 60% at soil field capacity with 0.5% hydrogel, quadrupled with 1% hydrogel, which is and with the greatest dose, raised more than twice as much of gelatin

(Fig. 1).The water contents of the polymer-affected soil consistently were greater than that of the undisturbed at a tugging pressure of pF. Finally, no significant changes were identified comparing the baseline sample and the soil modified with the smallest hydrogel dosages. Even with the greatest dosage of hydrogel (2%), the percentage of water in the soil was 10.1%, which was equivalent to the dampness of the unaltered soil at the field level. As a consequence, the findings reveal that the polymer-enhanced medium has a good reaction in terms of increasing. At an industrial scale, injecting a poly-acryl amide-based superabsorbent gelatin into soil composed of sand and clay boosted water retention by 60 to 100%, with the amount of hydrogel increasing the preservation of water. Similar findings were obtained on sandy soil treated with a hydrogel, albeit the hydrogel impact diminished as soil salinity rose, confirming a common issue with aesthetic hydrogels. Aside from the advantageous effects that higher water storage capabilities the effect that sandy substrates may have on the availability of water to plants, one recommended technique for avoiding water loss in sandy soils owing to drainage is to add polymers with hydrophilic properties to soils with low water retention, which has a significant influence on mitigation of potential causes of contamination of groundwater caused by fertilizer water diffusion in crop production regions.

3.2 Hydrogel's influence on the hydrology and physical characteristics of the material

The findings revealed that the hydrogel had a substantial influence on container capacity, with a 27.9% and 47.7% rise in WCC contrasted with unmodified perlite using 1% and 2% hydrogel, respectively, whereas no variations in AFP, BD, and TP were identified across treatments (Table 1). The increased substrate's ability to retain water under consideration was accomplished without sacrificing the large volume of air, which is a distinguishing property. Several granular perlites with other substrates. However, perlite's ability to store water is deemed extremely poor when compared to an ideal substrate, necessitating the use of this content in combination with components containing better water retention in most applications. The consequences of a new biopolymer employed for soilless substrate amendment revealed a considerable increase in soilless growth medium water availability. Although the findings suggest that it is feasible to improve. The water storage capacities of porous soilless substrates should be explored. It should be emphasized that growing plants without soil involves the use of fertilizer solutions, which raises the total salt content in the substrates. According to a research investigation involving the same group of hydrogel used in the present investigation, boosting electrical conductivity minimizes hydrogel swelling; thus, we can expect to be unable to improve the boards' capacity for water retention under real culture settings, particularly as the material's electrical resistance tends to go up as the growing process progresses.

According to the LSD test, the 5% level was not reached for the mean values in column separated by the same initials,

3.3 Hydrogel's Influence on the Growth of Plants

In the presence of the hydrogel, there were no indicators of phytotoxicity in the seeds of kinds of vegetables or ornamental plants. The Gindex was far over 60% on average for each of the 4 different animals examined (Fig. 2), which is the upper limit to deem the superabsorbent polymer investigated non-toxic. The species Centaurea had a very high Gindex both root development and the mean quantity of seed germinated in a hydrogel condition were much greater than in a non-gel condition. The lack in terms of phytotoxicity is the first necessity when considering the application of a novel substance as a constituent of the growth medium. In this light, we may consider the usage of this novel hydrogel to be completely safe for plants. The cucumber culture experiment results revealed that plants treated to hydrogel treatment grew faster overall at the time of investigation Growth parameters of cucumber plants depicts in Table 2. The vegetation had more completely fresh biomass leaf, stem, and biomass from fresh fruits, leaf area with the hydrogel.

The plants were cultivated using hydrogel and treated to regulate water stress. The leaf tissue was found to be more hydrated, as evidenced by a decreased proportion of dry substance in the leaves Effects of hydrogel depicts Fig. 3A. The increased possible water content of leaves value as well as turgor potential in the HYDROGEL treatment verified this conclusion leaf turgor potential depicts Fig. 3B and 3C. There were no variations in terms of leaf osmotic potential. Even in the absence of irrigation; the presence of hydrogel provided a certain level of water availability for the plants, resulting in increased leaf turgidity. The findings support the widely documented favorable advantages of hydrogels in promoting plant development and the decrease of the water stress has a detrimental impact. However, the variations in the substrates' water content steadily decreased after the study, suggesting probable modifications in the hydrogel's swelling ability. Previous research has found this behavior and is most likely linked to the repeated dryness and hydration cycles seen in vegetable irrigation and administration, as well as an increase in the saltiness of the substrate due to fertilizer salt contribution. However, the boosting expansion and restricting consequences of water stress reported throughout the early stage in the crop cycle remain strong, with major implications for the possible earliness of output. Plants for sweet basil planted based on perlite modified using hydrogel grew faster about newly harvested “biomass at DAS 46” Table 3 shows the fresh weight of sweet basil plants. However, the hydrogel's influence tended to be much reduced in the basil development cycle's latter phases, resulting in there are no major changes at 63 DAS. The increasing loss of efficiency of hydrogels used to describe plants in an envelope culture in soilless circumstances has been widely established.

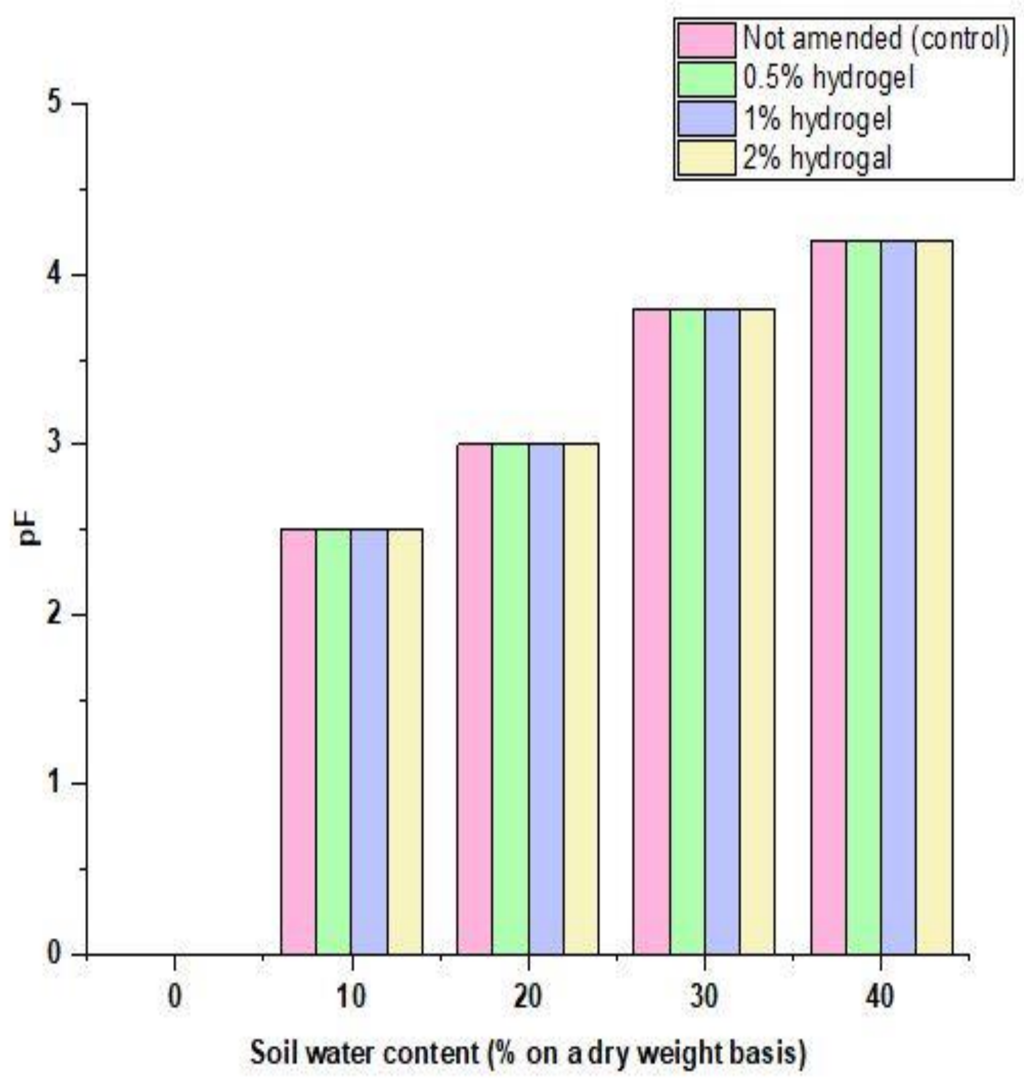

Fig. 1. The retention of the water curve of sandy soil that has not been altered or has been modified

Table 1. Total porosity (TP), air-filled porosity (AFP), and water container capacity (WCC)

Substrate	TP(% volume)	AFP(% volume)	WCC(% volume)	BD (g/cm^3)
Significance[1]	ns	ns	***	ns
Perlite	73.2	41.2	28.2 c	0.141
Perlite + 1% hydrogel	74.2	37.8	35.1 b	1.135
Perlite + 2% hydrogel	73.6	36.7	42.7 a	1.133

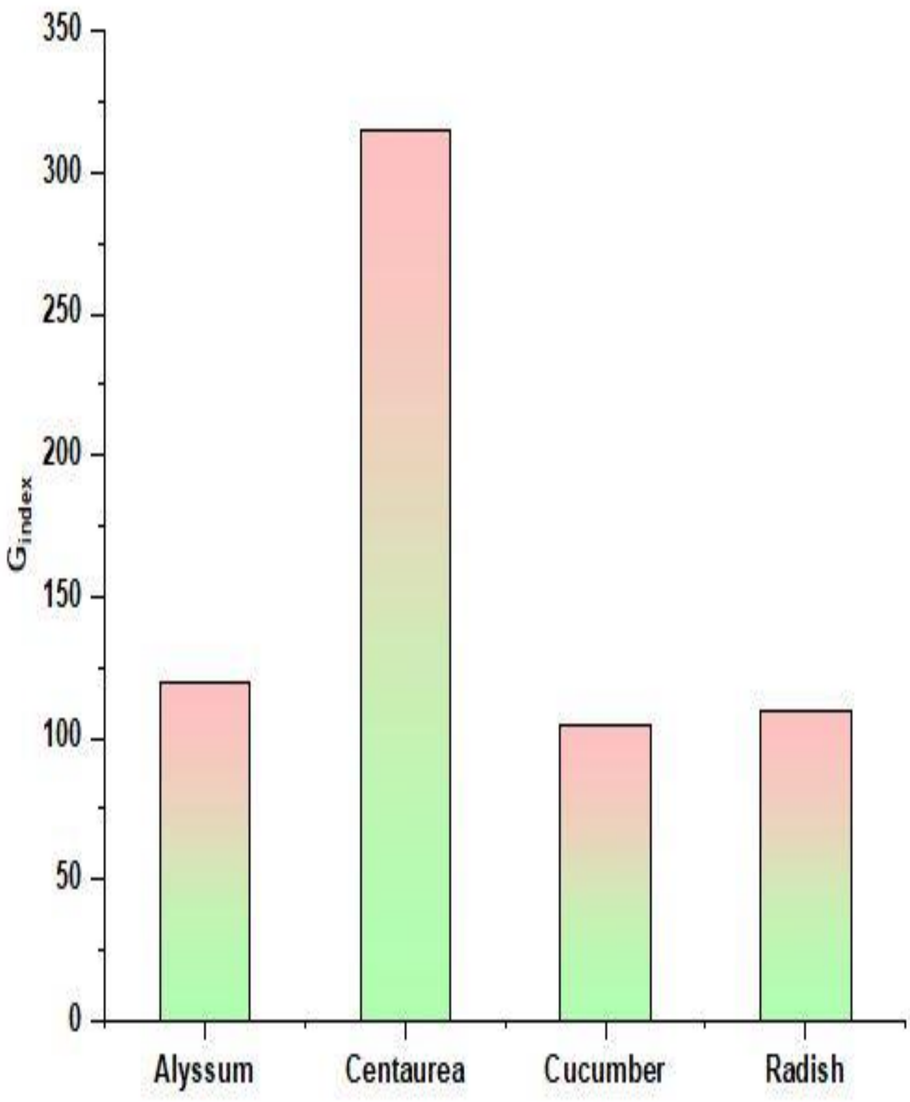

Fig. 2. Four species' germination indices (Gindices) that developed in the absence of a degradable hydrogel

Table 2. Growth characteristics of cucumber trees cultivated in sand without amendment or with amendment

Treatment	Leaf area (cm^2/plant)	Total fresh biomass (g/plant)	Stem fresh weight (g/plant)	Plant height (cm)	Leaf fresh biomass (g/plant)	Fruit fresh weight (g/plant)
Significance[1]	***	***	***	***	***	***
HYDROGEL	14276	1754	428	181	469	859
NO HYDROGEL	8771	914	265	159	286	365

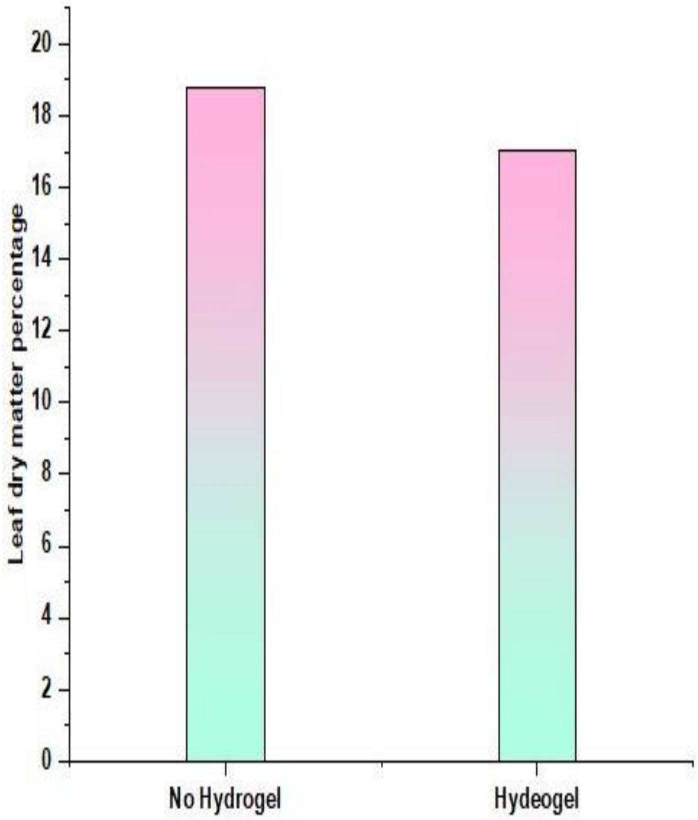

Figure 3(A). Hydrogel's effects on the percentage of dry leaves

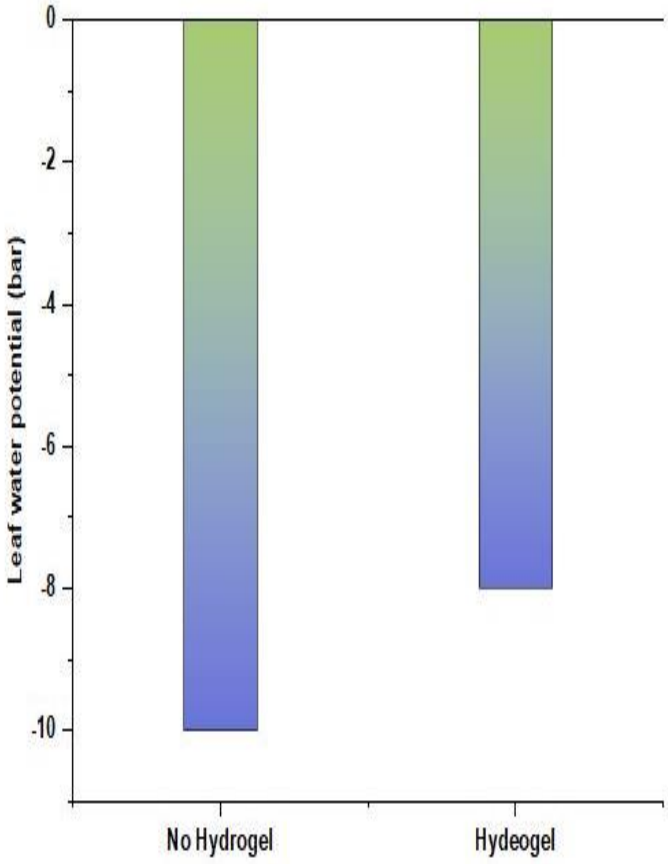

Fig. 3(B). Water content of leaves

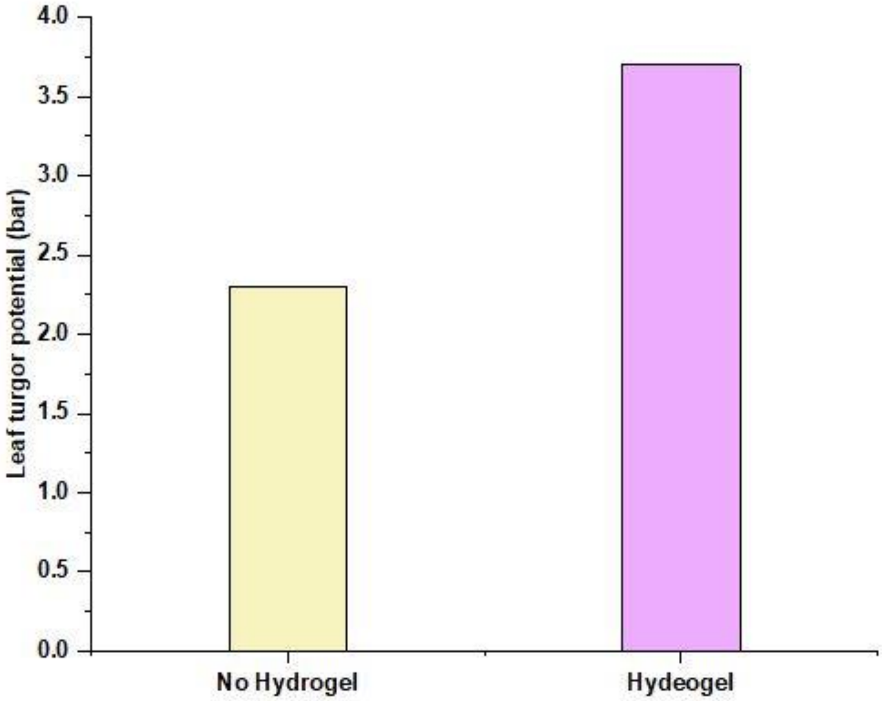

Fig. 3(C): Potential for leaf turgor

Table 3. Fresh weights of hydrogel-free or hydrophilic perlite-grown plants for sweet basil

"Perlite with hydrogel (%)"	"Fresh weight 63 DAS(g/plant)"	"Fresh weight 46 DAS (mg/plant)"
6	13.04	1330 a
Significance[1]	ns	***
0	11.44	750 b
3	12.64	1170 a

Theoretical studies on possible advantages of hydrogels discovered an early advantage in bedding plant containerized growing. Plant manufacturing is faster, but has not had much benefit later during planning and after-production. According to the LSD test, average values across columns separated by the same letters were not used substantially distinct in the 5% level not important; and ***, significant at a 0.1% level.

4. Conclusions

The novel hydrogel that was investigated in this study had the same good features as previous typical hydrogels, with the added benefit of being biodegradable. We found that sandy soil and perlite, both of which are known to have poor water retention substrates, had favorable impacts on plant development. Due to the frequent drying cycles of hydration and a high fertilization rate, soilless culture conditions may result in a steady loss of hydrogel efficacy. The evaluated hydrogel proved to be appropriate for possible agricultural usage, with a particular advantage for crops with limited growing seasons. Its use ought to be explored further from a cost-effective standpoint.

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