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Assessment of Bio-based Hydrogel as an Alternative Growth Medium for Seed Germination and Seedling Growth in Urban Farming

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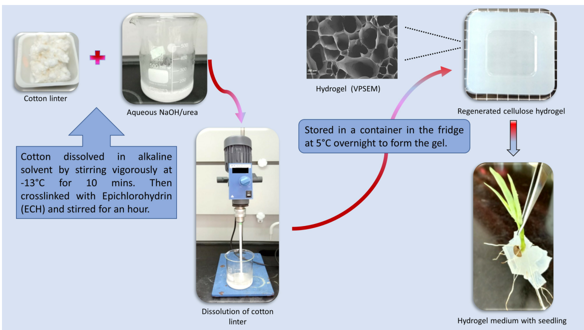
Abstract

Sustainable agriculture aims to meet the needs of the people in the present as well as in the future. The inadequate supply of vegetables raises dependency on imports for the growing population. To reduce import dependency, effective approaches in urban farming are emerging. One of the approaches is the application of hydrogel as a growth substrate in urban farming. This comparative study focuses on the characterisation of cellulose-based hydrogel sourced from cotton and its application as a seed germination medium in comparison to soil and perlite. Hydrogel is prepared by using cotton linter, sodium hydroxide, urea and epichlorohydrin as the cross-linker. Analyses to characterize soil, perlite and hydrogel (cryogel) were performed through gel fraction, field emission scanning electron microscopy (FESEM), X-ray diffractometry (XRD), attenuated total reflectance Fourier transform infrared (ATR-FT-IR) spectroscopy and thermogravimetric analysis (TGA). Seedling growth performance for four plant species (*Ipomoea aquatica, Brassica juncea, Lactuca sativa, Solanum lycopersicum*) was recorded after 15 days on each growth medium. Hydrogel crosslinking strength was at 92.49% based on gel fraction analysis and the swelling of the hydrogel reached 65% in 10 days. FESEM analysis shows the hydrogel has a porous structure. Growth of *Ipomoea aquatica* in hydrogel medium was better than in soil. Hydrogel medium has room for further improvement through future research and development in urban farming.

Keywords Cellulose · Epichlorohydrin · Cryogel · Soilless · Soil · Perlite· Precool method· Regenerated Cellulose

Graphical Abstract



1.0 Introduction

The growth of the world population has led to an increase in land urbanization and scarcity of fertile agricultural land for traditional agricultural activities. The United Nations Food and Agriculture Organization (FAO) predicts that by 2050, fertile land per person will decrease by one-third compared to 1970 (Benke and Tomkins 2017). Decreasing fertile land area may also impact food security and sustainability, especially in urban areas that depend on rural farming production. Thus, urban farming practice has been on the rise to address the potential risk. One of the latest trends is ultra-urban farming, often using vertical farming to bring farming and fresh produce to homes, office spaces, supermarket rooftops and above aisle spaces. Ultra refers to the revolutionary farming practice encouraging self-sufficiency and 'eat local' trends, the importance of which was clear during the recent Covid-19 pandemic era. This directly reduces dependency on vegetable importation and labour, reducing costs (Mahidin DSDMU 2017). Soilless farming also reduces damage while transplanting and cleaning (Husin et al. 2021).

There are several broad types of root growing medium used in urban farming, such as liquid medium (hydroponics), gas medium (aeroponics), and solid substrates (organic and non-organic substrates) (Wanas and Khamis 2021). In hydroponics, one of the approaches is to use hydrogel as a plant growth medium. Foliar spray treatments were performed on strawberry grown in traditional soil medium, mixed solid substrate medium and hydroponic (deep flow technique), with positive effects on plant growth (Wanas and Khamis 2021). Hydrogels have been produced by many methods and biomass materials with different processing, yet, limited studies have been carried out to determine the practicality in application.

Hydrogels originating from synthetic materials have been used in agriculture throughout the past five decades. Superabsorbent hydrogel originating from guar gum crosslinked by gamma radiation and added to dry red soil at 0.9% (polymer concentration) improved plant yields by 25.5% (Lokhande and Varadarajan 1992). In another study, three types of dry polymer made of polyacrylamide, polyvinyl alcohol and starch co-polymer were used individually (0, 0.1,0.2 and 0.5 % w/w) with oven-dried silica sand mixture under limited irrigation to grow pre-germinated seedlings of lettuce and barley for 16 days. The use of polyacrylamide superabsorbent polymer showed the greatest increase in dry weight at the 0.5 % w/w concentration compared to the control (Woodhouse and Johnson 1991). Hydrogel's ability to support plant growth in arid areas and assist in seed germination (Kabir et al. 2018) is also seen as a benefit. Hydrogel materials based on guar gum grafted on acrylic acid/acrylamide and acrylic acid/N-isopropylacrylamide copolymers with different weight ratios of guar gum with respect to acrylate monomers improved vegetative growth of guava plants (Abdel-Raouf et al. 2018).

Hydrogels are synthetic polymers or bio-based polymers that are chemically or physically cross-linked. The former type of hydrogels has permanent linkages while the latter has temporary linkages (Ahmed 2015). Hydrogels prepared from synthetic polymer are hydrophobic and mechanically more durable than the bio-based ones, resulting in a slower degradation rate (Rizwan et al. 2021). Meanwhile, natural polymers possessing features such as biodegradablility and lack of harmful contaminant residues have gained interest in agriculture (Kaco et al. 2014; Cui et al. 2019). Cotton linter is an industrial waste biomass and cellulose derived from it is one of the natural sources which has been applied in many fields, including material science, textile, cosmetic, pharmaceutical industries, medical equipment, health care and agriculture. In agriculture, cellulose-based products as a medium for seed germination and plant potting is an excellent substitute for non-renewable resources.

In this study, cellulose is the main renewable source as the starting material for hydrogel synthesis, with potentially strong benefits for the agriculture sector, to reduce the use of synthetic materials and promote green technology. However, natural polymer-based hydrogel, such as cellulose, has poor nutritional value for plants. Therefore, the use of hydrogel in combination with other soilless substrates such as coco peat, soil, vermiculite, pine bark and perlite is a common application to prevent soil-borne diseases (Dede et al. 2019; Tm et al. 2020). In addition, soilless substrates enhance plant growth by improving drainage and promote air circulation in the growth medium.

Seed germination plays a pivotal role in contributing to crop yield. The key requirements for seed germination are water, oxygen, light, and a suitable temperature. Under normal conditions, the stored nutrients in the cotyledon or endosperm of a seed in the form of proteins, lipids, and starch are hydrolysed through hydrolytic enzymes into simpler forms for uptake by the embryo (Ali and Elozeiri 2017). In recent advances, materials like nanoparticles, graphene and nanotubes have been employed to increase seed germination in soilless farming (Cao and Li 2021). Similarly, hydrogel has attracted attention as an alternative soilless medium owing to its unique feature as a water reservoir that facilitates seed germination and plant growth. The hydroxyl groups in the backbone of the cellulose polymer confer the hydrophilic characteristics and the substantial water absorbing capacity of hydrogel (Ahmed 2015; Salleh et al. 2021).

In this study, epichlorohydrin ECH cross-linked cellulose hydrogel sourced from cotton linter was compared to soil and perlite as seed germination media. The hydrogel was prepared by dissolving cellulose in an alkaline/urea solvent system. The resultant cellulose solution is then cross-linked by epichlorohydrin (ECH) via covalent linkages between the epoxy group of ECH and the hydroxyl group of the cellulose (Alam et al. 2019). This study aims to assess the material properties and the performance of cellulose-based hydrogel for seedling growth of of *Ipomoea aquatica, Brassica juncea,* *Lactuca sativa* and *Solanum lycopersicum* in comparison to soil (control) and perlite. The effects of the substrate material on germination, plant weight, leaf number are investigated and discussed. Hydrogel holds great potential in becoming a suitable medium for seed germination and plant growth. Moreover, the global demand for food can be enhanced by improving urban farming cultivation techniques using hydrogel.

2.0 Materials and Methodology

Cellulose from cotton linter was supplied by the school of Textile Science and Engineering, Tiangong University, Xiqing District, Tianjin, PR China. The cross-linker epichlorohydrin (ECH, C_3H_5ClO) (99%) was purchased from Sigma Aldrich, urea (CH_4N_2O), and sodium hydroxide (NaOH) purity of ≥ 96% were obtained from R&M Chemicals. Plant seeds were obtained from Lutie Nursery, Kajang, Malaysia. Soil (top soil: compost: sand; 3:2:1) and perlite were purchased from the Plant Biotechnology Lab, University Kebangsaan Malaysia. All of the chemicals were used without further purification.

2.1 Preparation of Cellulose Hydrogel

The hydrogel was prepared from a solvent solution consisting of NaOH / urea / H_2O solution (100g) in the ratio of 7:12:81 (w/w) with continuous stirring for 5 minutes. The solution was then kept in the freezer overnight. About 3% w/w (3g) of cotton was dissolved in the aqueous solvent at -13°C by stirring for about 10 minutes. To the resulting solution was added 10% w/w (10g) of cross-linker ECH and stirred continuously for about an hour to cross-link and produce a homogenous solution. The solution wast hen stored at 5°C overnight in a container.

2.2 Characterization of Germination Media

2.2.1 Gel fraction of hydrogel

The hydrogel was dried in the oven at 40°C until a constant weight was achieved. The dried gel was soaked in distilled water at 60°C for 48 hours, filtered and then dried again at 40°C in the oven until a constant weight was achieved before the gel fraction (GF) was calculated according to Salleh et al. 2019 using the following equation:

$$GF\% = \frac{Wd}{Wo} \; X\,100 \qquad (1)$$

where the W_o is the initial weight of the first dried hydrogel and W_d is the weight of the hydrogel after filtering and further drying.

2.2.2. Hydrogel water absorption

The initial weight of the wet hydrogel (Wi) was measured, then immersed in distilled water (changed daily) at room temperature until it reached an equilibrium weight at day 10. The weight was recorded each day until a constant weight was achieved. The absorption of water was calculated according to (Salleh et al. 2019) using the following equation :

$$Water\ absorption\ (\%) = \frac{Wc - Wi}{Wi}\ X\ 100 \qquad (2)$$

where Wi is the hydrogel weight before immersion and Wc is the hydrogel weight after immersion in the distilled water until it reaches an equilibrium weight.

2.2.3. Hydrogel reswelling studies

The reswelling study was conducted using freeze-dried hydrogel known as cryogel. Cryogel at equilibrium in weight was immersed in 500 mL of distilled water for 2 hours before the weight was recorded again. The immersed cryogel was then air-dried at room temperature, then described as xerogel, and weighed. The reswelling and air-dry cycles were repeated for 4 cycles. The reswelling was calculated in percentage according to (Salleh et al. 2019) using the following equation :

$$Reswelling\ rate\ (\%) = \frac{Wc}{Wi}\ X\ 100 \qquad (3)$$

where Wi is the hydrogel weight before immersion in distilled water and Wc is the hydrogel weight after air-drying.

2.2.4. X-ray diffractometry (XRD) analysis

The XRD analysis was carried out on cotton linter and freeze-dried hydrogel (cryogel) characterized using Bruker Advanced X-ray Solutions D8 diffractometer and the software DIFFRAC^{Plus} Evaluation (EVA) was used to calculate the crystallite size. The cotton linter and 1mm thin slice of freeze-dried hydrogel samples were used to fill the sample holder and pressed gently with a glass slide to ensure a flat surface. The measurement parameters of the XRD characterizations with a diffraction angle (2θ) from 5°- 60°, CuKα radiation (λ = 0.15418 nm), stepsize of 0.04, time per step at 1.2 sec (fast detector), detector type of 1-D Fast detector and scan type of locked couple (θ-2θ scan). Furthermore, in order to determine the area under the peaks, the peaks FWHM (full-width at half-maximum) and to subtract the baseline, the curves were deconvoluted by applying Voigt fitting procedure using Origin software (Caputo et al. 2019 ;). Rico del Cerro et al. 2020)

The technique used by the EVA software to calculate crystallinity is by the following equation (Gan et al. 2015) :

$$CrI\ (\%) = \frac{A\ crystal}{A\ total}\ X\ 100 \qquad (4)$$

where $A_{crystal}$ is the sum of the areas under the crystalline diffraction peaks and A_{total} is the total area under the diffraction curve between 2θ = 5° – 60°.

The crystallite size was calculated using Scherrer's equation as below:

$$L = \frac{k\ \lambda}{\beta \cos\theta} \qquad (5)$$

where L is the size of crystallite (nm), k is the Scherrer constant (0.94), λ is the X-ray wavelength (0.15458 nm), β is the full width half maximum (FWHM) and θ is the Bragg angle (Diarsa and Gupte 2021).

2.2.5 Field Emission Scanning Electron Microscope (FESEM)

The morphology and porosity aspects of the germinating media, i.e., soil, perlite and cryogel, were observed under the field emission scanning electron microscopy (FESEM, Supra 55VP, Zeiss), using high vacuum mode, 10kV of acceleration voltage. Soil and perlite samples were prepared by mounting on aluminium stubs and dried in an oven at 34 °C for an hour before gold-coating of 6nm thickness. The cryogel sample was prepared into a size of 2 cm x 2 cm x 1 cm, mounted on aluminium stubs and gold-coated for 6nm of thickness.

2.2.6 Attenuated Total Reflectance Fourier Transform Infrared (ATR-FT-IR) Spectroscopy Analysis

ATR-FT-IR analysis was performed using a Bruker ATR-FT-IR spectrometer. The soil, perlite and cryogel samples were analysed from 4000 to 600 cm^{-1} with 64 scans, and the measurement of resolution was set to 4 cm^{-1}.

2.2.7 Thermogravimetric Analysis (TGA)

Thermal stability studies were performed using a Netszch STA 449 F3 Jupiter instrument. The temperature range used was from 25 to 600 °C with a heating rate of 10 °C/min conducted in nitrogen atmosphere. The sample amount for soil, perlite and hydrogel (cryogel) was 13.77mg, 19.33mg and 5.78mg respectively.

2.3 Seed Germination Percentage, Plant Weight and Leaf Number Determination

Seeds of *I. aquatica, B. juncea, L. sativa* and *S. lycopersicum* were sown in soil (control), perlite and hydrogel medium each with 50 seeds and three replications, arranged in a completely randomized design. Seed germination was carried out in the growth room at 22°C under a 4000 K LED light source with a photoperiod of 16 h/8 h, light/dark. The seeds were considered to have germinated upon radicle protrusion of 1-2 mm. Average fresh weight of the plant and leaf number were recorded for the best uniform 10 seedlings out of 50 seeds in each replication. The seed germination percentage results were obtained in previous work (Palanivelu et al. 2021), and average plant weight (g) and total leaf number for each plant species were recorded after 15 days. Statistical analyses were performed by comparing the mean using two-way ANOVA.

3.0 Results and Discussion

3.1 Hydrogel Swelling and Reswelling Capabilities

The cellulose-based hydrogel was sourced from cotton linter whereby thousands of β (1-4) linked D-glucose units in the cellulose chain carry many hydroxyl groups (Zainal et al. 2021). ECH serves as the cross-linker in hydrogel formation, leading to the completion of cross-linking (Chang et al. 2010; Kayra and Aytekin 2018). The hydrophilic functional group, such as -OH aid in water absorption and water retention (Zhang et al. 2017; Kabir et al. 2018). The porous structure of hydrogel (Fig. 1c) which has interconnected open cells provides larger surface area for better absorption of water and swelling (Ahmed 2015).

Gel fraction corresponds to the stability of a hydrogel. The high intermolecular forces of the cross-linked network of cellulose contributed to the high gel fraction value (Salleh et al. 2019). The gel fraction of the prepared hydrogel reveals 92.49%, which is tolerant to heating to 60 °C in water. The value indicates that the formed cross-linking network is sufficient to resist dissolution by external forces or in extreme conditions. The high gel fraction value enables the hydrogel to swell and maintain the structure without rupturing. These physical properties of hydrogel reflect in the abilities of swelling and reswelling, as shown in Fig. 2.

The swelling of hydrogel through water absorption is crucial for hydrogel to release the stored water to meet the requirement of the seedlings. Water absorption by the hydrogel is due to the capillary action, osmosis, and hydration force in the cellulose hydrogel. This involves binding the water molecule to the hydrophilic hydroxyl groups along with the cellulose polymer network, which is formed through inter-molecular, intramolecular hydrogel bonds in the cellulose molecule (Salleh et al. 2021). The hydration of the hydroxyl group (primary bound water) leads to the swelling of the network, exposing hydrophobic groups to interact with water (secondary bound water) (Parhi 2017). Hydrogel swelling analysis shown in Fig. 2a shows that the swelling rate increased by 65% in ten days before achieving an equilibrium weight. The swelling rate increased by 5.47% within the first 24 hours, from 40.71% on day one to 46.18%. The hydrogel produced is highly alkaline hence was rinsed by soaking in distilled water in order to neutralize it. The ions between two different phases will be exchanged during the neutralisation process, making the polar, hydrophilic groups hydrated. The water that is bound with the polar groups is the primary bound water. As the water absorption takes place rapidly, the polar group is fully hydrated, which led to the swelling of the hydrogel network. As the hydrogel network expands, the hydrophobic groups are also exposed and tend to engage with the water molecules, known as hydrophobically-bound water or secondary bound water. After complete water absorption, the equilibrium swelling is achieved with the retraction force from the covalently cross-linked network (Salleh et al. 2019).

Hydrogel reswelling shown in Fig. 2b illustrates the ability of the hydrogel to reswell in the event of drying due to insufficient water availability during plant growth. The highest reswelling of 57.66% is seen after the first cycle, and the subsequent drying cycles in the air at room temperature show consecutive reswelling below 10%. The freeze-dried hydrogel, known as ‘cryogel’ (Buchtová and Budtova 2016; Salleh et al. 2020) and has an opaque, porous structure, as shown in Fig. 2d. The freeze-dried hydrogel absorbs water better than air-dried hydrogel (‘xerogel’) because of its porous structure (Simoni et al. 2017). The structure of xerogel collapses and becomes thin during the air-drying process at room temperature, as shown in Fig. 2e

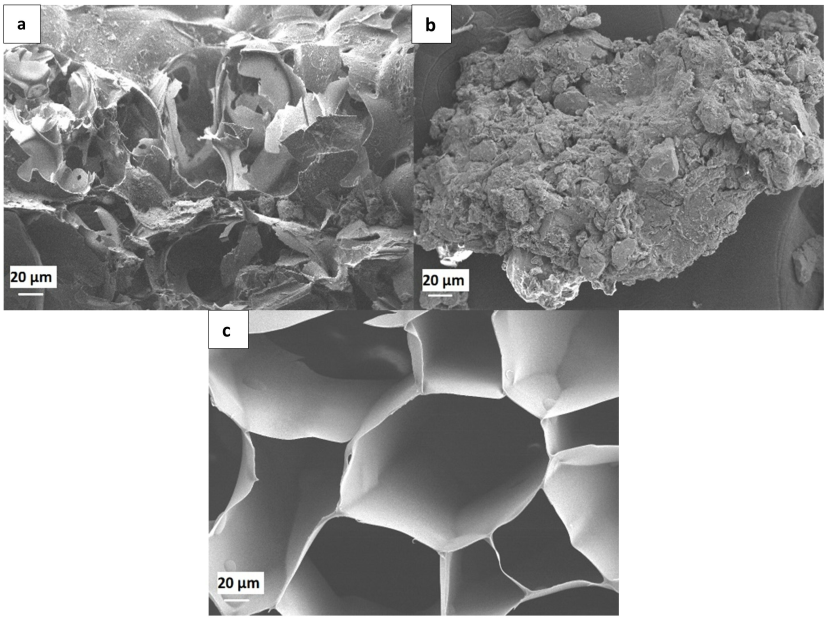


Fig. 1 FESEM of **(a)** soil **(b)** perlite **(c)** hydrogel (cryogel)

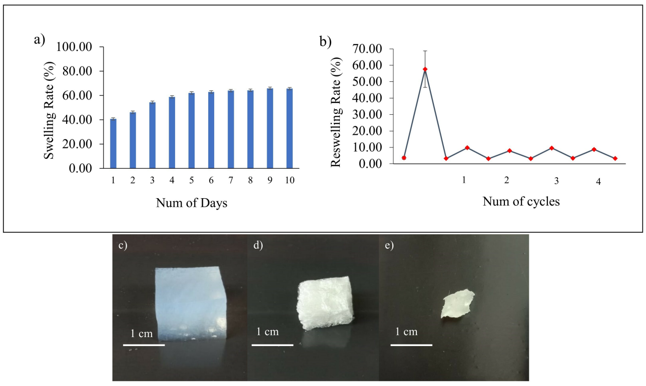


Fig. 2 **a** Hydrogel swelling over ten days **b** Hydrogel reswelling for 4 cycles **c** Hydrogel after neutralisation at initial stage **d** Freeze-dried hydrogel (cryogel) **e** Air- dried hydrogel (xerogel)

3.2 X-ray Diffractometry (XRD) Analysis

XRD of cotton linter and cryogel was obtained to observe the phase transition of cellulose and to identify their crystallinity and crystallite size. The XRD diffractogram is as shown in Fig. 3. By using EVA software, the cotton linter shows cellulose I form with the peaks at 2θ =14.80°, 16.68°, 22.99° [Miller indices of (1-10), (110) and (200), respectively] (French 2014; Gan et al. 2015) while the cellulose II peaks appear in hydrogel (cryogel) at 2θ = 19.87°, 22.07° [Miller indices of (110) and (020) respectively] (Gan et al. 2015). The hydrogel (cryogel) has proven to have the crystalline structure of cellulose II. The rearrangement of dissolved cellulose macromolecules via a randomised crosslinking process of dissolved cellulose macromolecules by ECH has transitioned them into cellulose II (Chang et al. 2008). The crystallite size of cotton linter is 5.07 nm (50.7Å), and hydrogel's single broad peak is 1.61 nm (16.1 Å). It is reported that when the peak in the diffractogram is broad, the crystal size will be small and when the observed peak is sharp the crystal sizes will be big (Scherrer 1918; French 2020). By using Origin software, after the baseline correction and deconvolution the crystallinity index of cotton linter is 95.78% and hydrogel is 98.90%.

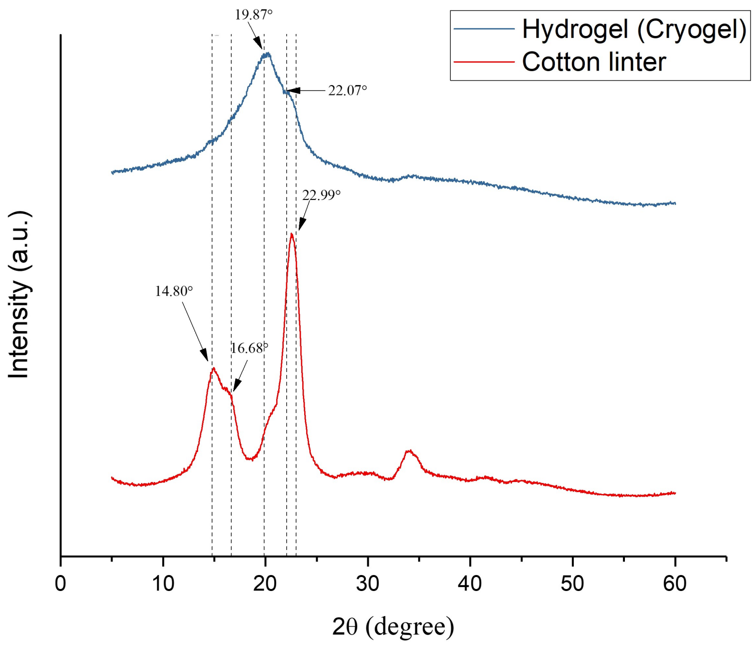


Fig. 3 X-ray diffractometry of cotton linter and hydrogel (cryogel)

3.3 Attenuated Total Reflectance Fourier Transform Infrared (ATR-FT-IR)

The ATR-FTIR characterizations can determine the functional groups in a material revealing its chemical properties. Previous studies describe the appearance of certain bands in the spectrum that demonstrate cross-linking and the presence of functional groups. The band at 3380 cm^{-1} occurs for cotton linter and cryogel, indicating the O-H stretching of cellulose (Oun and Rhim 2015). Similarly, the peak at 2904 cm^{-1} wavelength for cotton linter and cryogel is the C-H stretching vibration (Oun and Rhim 2015). The region between 1250 to 950 cm^{-1} is where the cross-linking occurs between cellulose and ECH, forming new ether bonds and secondary alcohols in the β-hydroxypropyl ether bridges. After the cross-linking, ECH reactivity is observed through the change at 1260 cm^{-1} due to the decrease in epoxy functionality. A reduction of hydrogen bonding in the hydrogel (cryogel) could be observed in the region 3600-3000 cm^{-1} because of the strong covalent bonding. A transformation in the OH bonds is obvious in the region of 3000-2800 cm^{-1} (Huber et al. 2019). These findings are parallel to the XRD phase transition in cryogel formation, confirming the rearrangement of cellulose during cellulose dissolution and further confirming the ECH cross-linking.

The successful seed germination in perlite is speculated due to the better aeration provided by silicon composition in the material. In the FT-IR characterization of perlite, the peaks at 3445 and 1632 cm^{-1} belong to the stretching and bending modes of -OH in the Si-OH group, while the bending at 1063 cm^{-1} is due to the presence of Si-O

(Chegeni et al. 2021). The wavelength 802 cm^{-1} is the Si-O-Si stretching attributed to the amorphous silica (Kabra et al. 2013).

In soil, the absorbance bands at 2925, 2858 and 1730 cm^{-1} correspond to soil humic compounds, which represent the organic content in the soil; while the 1050 cm^{-1} band represents the Si-O stretching (Cox et al. 2000).

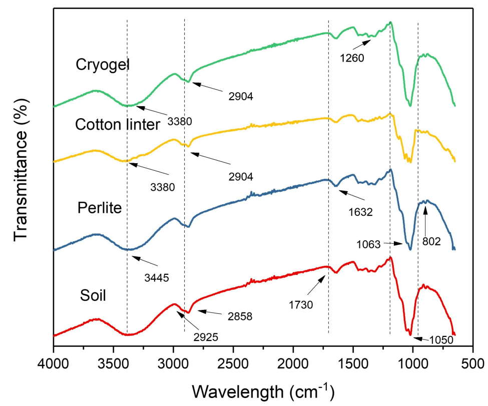


Fig. 4 FTIR spectra of cotton linter (yellow line), soil (red line), perlite (blue line) and cryogel (green line)

3.4 Thermogravimetric Analysis (TGA)

Thermal analysis is used to test the thermal stability of the media. Differences in thermal behaviour provide insights into energy interactions between the organic components with temperature changes. The TGA and DTG curves of soil, perlite and cryogel were compared (Fig. 5). The very first stage is the loss of volatile components such as moisture, monomers, and solvents. Next is decomposition, followed by changes in the atmosphere from nitrogen to oxygen. Then, carbon combustion takes place, leading to inert inorganic residues of ash. In this study, in cryogel, a small amount of weight is lost at 100-200 °C owing to moisture loss. At 382-400 °C a large weight reduction of -85.7% is seen, representing total degradation due to disintegration of the molecular structure. In perlite, the weight began to reduce at 53-400 °C. After 550 °C, the weight loss is due to the combustion of carbonaceous materials (Kabra et al. 2013). As for the soil sample, the weight began to reduce at 80-180 °C due to moisture loss with total degradation at 300-600 °C. The bell shape graph of the weight derivative indicates low thermal stability of hydrogel. Residual mass for cryogel, perlite and soil are 8.5%, 91.6%, and 90.7% respectively. Hypothetically, a lower residual value indicates lower thermal stability (Salleh et al. 2019). It is shown that the cryogel is not thermally stable in comparison with soil and perlite. This indicates hydrogel (cryogel that has absorbed water) is environmentally friendly and easily degradable.

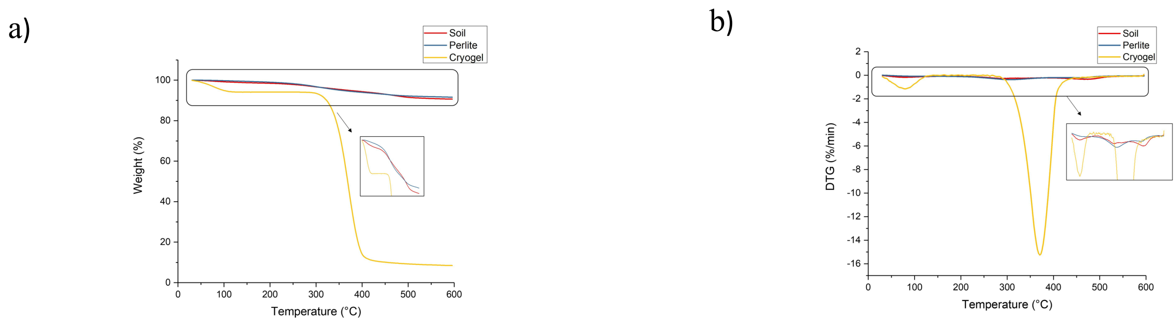


Fig. 5 a) TG and b) DTG curves of **s**oil, perlite, cryogel

3.5 Seedling Growth Performances

The hydrogel performance in plant growth was assessed based on the seed germination rate, plant weight, and leaf number. In our previous work, the highest germination rate in the hydrogel was observed for *B. juncea* at 70.67% followed by *L. sativa* at 70.00%, with no significant difference between them ($p < 0.05$) (Palanivelu et al. 2021). The ability of *B. juncea* and *L. sativa* to germinate in the hydrogel is mainly due to water availability to the seeds. Water imbibition hydrates the seed, activating metabolic processes required for germination and seedling development, and is used to drive seedling growth. Subsequently, water reservoirs promote establishment of the seedling roots (Jampi et al. 2021). Therefore, water availability is advantageous in hydrogel as an alternative medium for seed germination. In regard to hydrogel, a significant utility can be anticipated as a suitable medium for seed germination in urban farming, subject to further optimization.

In perlite, *S. lycopersicum* has the best germination rate at 90.67% (Palanivelu et al. 2021). Perlite is a lightweight natural volcanic glass containing alumina-silicate minerals (GÜL 2016). It appears in agglomerates, as shown in Fig. 1b, which is used extensively in soilless culture as a substrate in combination with peat moss, compost, bark, or coconut coir (Gohardoust et al. 2020). Perlite has better aeration (Tm et al. 2020), compared to the more drained and compacted soil due to its small particle size (Abu-Shahba et al. 2021). Although silicon is not considered a major nutrient for plant growth, the element in perlite has been reported to benefit plant growth, especially under salt stress (Solatni et al. 2012; Gou et al. 2020). In addition, seed germination of tomatoes was improved when using silica nanoparticles (Luyckx et al. 2017).

The highest germination rate in soil observed for *B. juncea* was 74.67% (Palanivelu et al. 2021). The FESEM image of soil in Fig. 1a shows a densely packed arrangement. The seed germination and seedling growth in soil were not only influenced by the availability of water. The top soil composition holds the upper layer of soil with organic matter and microorganisms besides the compost. The sand composition promotes drainage and creates space in the soil for aeration. The different composition of minerals and microbial activities in the soil has been shown to influence plant growth (Djidonou and Leskovar 2019; Lei and Engeseth 2021). The microbes in the soil can impact seed germination (Walsh et al. 2021) and can promote plant growth. The mechanisms by which the microbes help the plant growth are not known clearly, but in general, it has been postulated by three mechanisms, firstly by manipulating the hormonal signals of plants, secondly by resisting pathogenic microbial strains, and thirdly by increasing the bioavailability of the soil-borne nutrients (Jacoby et al. 2017).

As shown in Fig. 6 by species, *I. aquatica* has grown significantly better in perlite compared to soil. The weight of *I. aquatica* seedlings in the hydrogel was comparable to that of perlite, indicating that hydrogel medium can be a suitable medium for *I. aquatica* seedling growth. The weight of *B. juncea* seedlings grown on hydrogel was significantly lower the the seedlings grown on soil and perlite, while the highest seedling weight was observed in soil. A similar result was also observed in *S.lycopersicum*. *L. sativa* seedlings showed no significant difference in weight in soil and perlite, with the highest weight observed in perlite, while seedlings grown on hydrogel showed the lowest weight. Thus, *I. aquatica* and *L. sativa* plant species grow best in perlite in terms of seedling weight. This could be due to naturally occurring nutrients in perlite. On the other hand, *B. juncea* and *S. lycopersicum* showed the highest seedling weight in soil. Soil is the conventional growth medium and provides a nutrient-rich environment for seedlings. Hydrogel medium has the potential to be a growth medium for healthier seedlings upon germination with more modification in terms of infused nutrients and conducive medium.

The leaf numbers produced (Fig. 7) follow a similar trend as plant weight. *I. aquatica* obtained the highest leaf number in perlite. In *B. juncea*, soil provides the best growing medium where it is perlite for *L. sativa* and *S. lycopersicum.* The growth rate in hydrogel medium is generally lower compared to soil or perlite. This could be due to the lack of minerals in hydrogel and the poor aeration for oxygen, although it possesses a porous structure. The water molecules in the porous structure may have impeded the presence of gaseous oxygen.

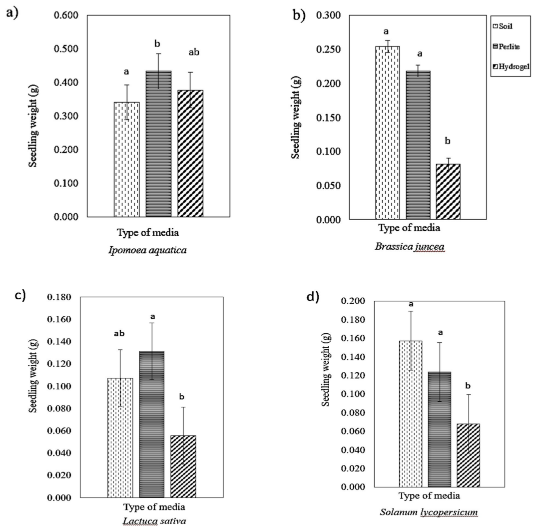


Fig.**6** Plant weight of a) *Ipomoea aquatica* b) *Brassica juncea* c) *Lactuca sativa* d) *Solanum lycopersicum* after growth on the three media for 15 days. Letters indicate significant differences between growth media for each plant species with $P < 0.0001$, n= 150

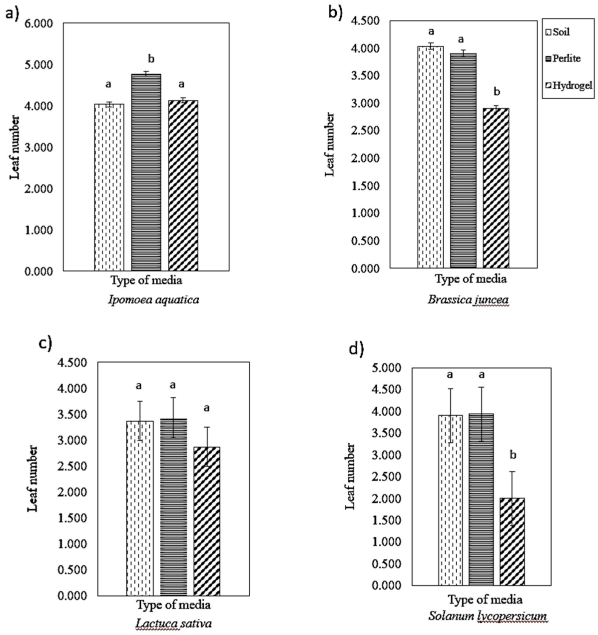


Fig.**7** Leaf number of a) *Ipomoea aquatica* b) *Brassica juncea* c) *Lactuca sativa* d) *Solanum lycopersicum* after growth on the three media for 15 days. Letters indicate significant differences between plant species with $P < 0.0001$, n= 150.

4.0 Conclusions

Limited fertile land and sustainable water consumption restrict agricultural production within urban areas. Cellulose-based hydrogel provides an alternative solution while addressing the zero-waste approach. Hydrogel medium supports seed germination in different species tested. The ability to reswell upon drying the hydrogel showed a valuable and promising characteristic of a plant growth medium for sustainable farming. The porous structure of the hydrogel which is evident in FESEM analysis allowed the roots of the seedling to anchor in a well-aerated medium.

Hydrogel is a suitable medium for urban farming to replace other soilless substrates. The germination rate and material characterizations here suggested that hydrogel has prospects as an alternative medium for soilless plant cultivation. In the future, a more customised hydrogel with better features such as better aeration and nutrient supply will further improved the seed germination rate and plant growth rate.

Statements and Declarations

Compliance with ethical standards and consent to participate

Informed Consent

Not applicable.

Consent for publication

Consent for publication was obtained from all the authors.

Availability of data and materials

The data presented in this study are available on request from the corresponding author.

Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

Conflict of interest

The authors declare that they have no conflict of interest.

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Authors' information (optional)

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