Eichhornia crassipes-Based Hydroponic Growth Medium: A Sustainable Approach to Plant Cultivation and Resource Valorization

ABSTRACT

The increasing demand for sustainable food production has intensified the search for biodegradable and cost-effective alternatives to conventional hydroponic growing substrates. The present study investigated the potential of *Eichhornia crassipes* (water hyacinth) biomass incorporated with carboxymethyl cellulose (CMC) as a biodegradable hydrogel substrate for the cultivation of *Vigna radiata* L. An aqueous extraction method was employed to recover polymer from *E. crassipes*, yielding approximately 10% polymer with a pH of 6.0. The extracted polymer was incorporated with CMC to develop an *Eichhornia*-CMC hydrogel, and its performance was compared with CMC hydrogel and conventional soil. Seed germination, seedling vigour, shoot and root growth, leaf development, chlorophyll content, water retention, biochemical composition, mineral accumulation, and endogenous auxin content were evaluated. The *Eichhornia*-CMC hydrogel promoted rapid seed germination and superior seedling development, with a Seed Vigour Index of 382 compared with 287 and 370 in CMC hydrogel and soil, respectively. Plants cultivated on the *Eichhornia*-based hydrogel exhibited higher shoot and root lengths, leaf area (4.0 cm^2), chlorophyll content (0.872 mg g^{-1}), ash content (3.65 g), and water content (53.33%). Enhanced carbohydrate (0.045 mg g^{-1}), protein (0.050 mg g^{-1}), and lipid (0.003 mg g^{-1}) contents were also recorded. The extracted polymer contained detectable endogenous auxin ranging from 4.2 to 4.6 µg mL^{-1}, suggesting additional plant growth-promoting potential. Overall, the findings demonstrate that *Eichhornia*-CMC hydrogel can serve as a promising biodegradable hydroponic substrate while simultaneously valorizing invasive aquatic biomass and supporting circular bioeconomy approaches in sustainable agriculture.

Keywords

Eichhornia crassipes; *Vigna radiata*; hydroponics; biodegradable hydrogel; carboxymethyl cellulose; invasive aquatic weed; seedling vigour; plant growth; sustainable agriculture; biomass valorization.

INTRODUCTION

Hydroponics is an advanced soilless cultivation system in which plants are grown in nutrient-enriched aqueous solutions rather than soil. Its efficient utilization of water, nutrients, and cultivation space has established hydroponics as a promising alternative to conventional agriculture (Resh, 2013; Jones, 2016). Compared with traditional farming, hydroponic systems can improve crop productivity while reducing water consumption, nutrient losses, and soil-borne pests and diseases (Barbosa et al., 2015; Gruda, 2019). These advantages are particularly relevant in regions affected by water scarcity, soil degradation, urbanization, and declining arable land resources (Shamshiri et al., 2018). Recent advances in controlled-environment agriculture, including automation, artificial intelligence (AI), Internet of Things (IoT)-based monitoring, and renewable energy technologies, have further improved environmental control, crop quality, and year-round production (Benke & Tomkins, 2017; Shamshiri et al., 2018). Consequently, hydroponics has gained increasing importance for the production of vegetables, herbs, and microgreens with high nutritional and commercial value (Touliatos et al., 2016).

Despite these advantages, the widespread adoption of hydroponics is limited by the cost and environmental implications of conventional growing substrates such as rock wool, cocopeat, vermiculite, and perlite. Although these materials provide physical support and water-holding capacity, their production, transportation, and disposal can increase production costs and environmental burdens (Gruda, 2019; Barrett et al., 2016). Therefore, the development of biodegradable, renewable, and economically viable substrate alternatives has become an important research priority (Putra &Yuliando, 2015). *Eichhornia crassipes* (Mart.) Solms, commonly known as water hyacinth, is a highly invasive aquatic macrophyte native to the Amazon Basin. Its rapid proliferation produces dense floating mats that reduce dissolved oxygen, restrict light penetration, disrupt aquatic biodiversity, and interfere with navigation, irrigation, and fisheries (Villamagna& Murphy, 2010; Malik, 2007). Conventional management approaches, including mechanical, chemical, and biological control, are often costly and provide only temporary control (Gopal, 1987; Villamagna& Murphy, 2010).

Valorization of *E. crassipes* biomass into value-added products offers an alternative strategy for addressing this environmental problem. Its fibrous biomass possesses favourable characteristics such as porosity, water-holding capacity, biodegradability, and nutrient-retention potential, making it a promising renewable material for agricultural applications

(Rezania et al., 2015; Mishima et al., 2008). Such biomass utilization can simultaneously support invasive-weed management, waste minimization, and circular bioeconomy principles (Rezania et al., 2015; Kumar et al., 2020). Natural polymers have also attracted considerable interest in sustainable agriculture because of their biodegradability, biocompatibility, and moisture-retention properties (Ahmed, 2015). Carboxymethyl cellulose (CMC), in particular, is widely used in hydrogel development owing to its swelling capacity, structural stability, and water-retention properties (Chang & Zhang, 2011; Sarkar & Walker, 2015). Incorporating *E. crassipes* biomass into a CMC-based hydrogel may therefore provide a sustainable substrate with improved moisture retention and favourable conditions for root development.

Mung bean (*Vigna radiata* L.) is an economically important pulse crop characterized by rapid growth, high nutritional value, and widespread use as sprouts and microgreens (Dahiya et al., 2015; Tang et al., 2014). Its short growth cycle and responsiveness to cultivation conditions make it a suitable model for evaluating novel growing substrates (Nair et al., 2013). Therefore, the present study developed an eco-friendly hydrogel from *E. crassipes* polymer and CMC and evaluated its suitability as a hydroponic growing medium for *V. radiata*. Seed germination, seedling vigour, vegetative growth, chlorophyll content, biochemical composition, and mineral accumulation were assessed and compared with CMC hydrogel and conventional soil. The study aims to demonstrate the potential of invasive *E. crassipes* biomass as a biodegradable hydroponic substrate while contributing to sustainable agriculture, environmental conservation, and circular biomass utilization.

MATERIALS AND METHODS

Chemicals

All analytical-grade chemicals and reagents used in this study were procured from HiMedia Laboratories Pvt. Ltd. (India) and Merck Ltd. (India). All solutions were prepared using distilled water.

Plant Materials

Healthy *Eichhornia crassipes* plants were collected from the freshwater lake at Porur, Chennai, Tamil Nadu, India. Fresh seeds of *Vigna radiata* L. were purchased from a local market and used throughout the study.

Preparation of *Eichhornia crassipes* Biomass

The collected *E. crassipes* plants were thoroughly washed three times with distilled water to remove adhering mud, algae, and other impurities. The cleaned biomass was chopped into small pieces and dried in a hot-air oven at 50°C until a constant weight was achieved. The dried material was pulverized into a fine powder using a laboratory grinder and stored in airtight containers at room temperature until further use.

Extraction of *Eichhornia crassipes* Polymer

An aqueous extraction method was employed to isolate the polymeric fraction from *E. crassipes*. Five grams of dried biomass powder were suspended in 500 mL of distilled water and incubated in a rotary shaker for 12 h. The suspension was subsequently autoclaved atm121°C (15 psi) for 30 min to facilitate polymer extraction. After cooling, the extract was filtered through muslin cloth followed by Whatman No. 1 filter paper. The filtrate was transferred to sterile Petri dishes and dried at room temperature for 3–4 days. The dried polymeric film was carefully scraped from the Petri dishes, weighed to determine extraction yield, and stored at 4°C for subsequent analyses.

The extraction yield was calculated using the following equation:

Polymer Yield (%) = (Weight of dried polymer / Weight of dried plant material) × 100

Preparation of *Eichhornia*-CMC Hydrogel

A biodegradable hydrogel was prepared by dissolving 3% (w/v) carboxymethyl cellulose (CMC) in distilled water. To this solution, 5% (w/v) *Eichhornia* polymer and 1% (v/v) Panchakavya were added under continuous mechanical stirring for 30 min to obtain a homogeneous hydrogel. The prepared hydrogel was stored at 4°C until use.

Seed Germination and Hydroponic Cultivation

Mung bean (*Vigna radiata* L.) seeds were soaked overnight in distilled water to initiate hydration. The soaked seeds were wrapped in moist muslin cloth and incubated for 24 h to allow germination.

Three experimental growth media were evaluated:

1. Conventional soil (control)
2. CMC hydrogel
3. *Eichhornia*-CMC hydrogel

Equal quantities of each growth medium were transferred into paper cups. Germinated seeds were uniformly placed on the respective media and covered with moist muslin cloth. The cultures were maintained under dark conditions for four days to facilitate early seedling establishment and subsequently transferred to natural daylight for further growth. Plants were harvested at the microgreen stage for biochemical and physiological analyses.

Preparation of Plant Extract

Freshly harvested *Vigna radiata* plants were homogenized with distilled water using a sterilized mortar and pestle. The homogenate was filtered through muslin cloth followed by Whatman No. 1 filter paper. The filtrate was used immediately for biochemical estimations.

Biochemical Analyses

Total carbohydrate content was determined using the Anthrone method with glucose as the standard. Absorbance was measured at 620 nm using a UV–Visible spectrophotometer. (David T. Plummer 1990)

Total protein content was estimated according to the Lowry method using bovine serum albumin (BSA) as the standard. Absorbance was recorded at 750 nm. (Van Handel, M. T. 1985)

Total lipid content was determined using the vanillin–phosphoric acid colorimetric assay. Lipid concentration was calculated from a standard calibration curve after measuring absorbance at 540 nm. (Corby-Harris, V.,2024)

Estimation of Auxin

Endogenous auxin (indole-3-acetic acid, IAA) present in *Eichhornia crassipes* extract was quantified using the Salkowski colorimetric method. The reaction mixture was incubated at 37°C for 30 min, and absorbance was measured at 530 nm. Auxin concentration was calculated from a standard curve prepared using known concentrations of IAA.(Guardado-Fierros, B. G.,et.al 2024;Das, S.,et.al 2019).

Determination of Ash Content

The mineral content of *Vigna radiata* leaves was estimated by determining total ash content. Accurately weighed plant samples were incinerated in a muffle furnace at 500–600°C until constant weight was obtained. Ash percentage was calculated using standard gravimetric procedures. (Bhardwaj, S et.al.,2010; Pathak, N et.al.,2013)

Fresh and Dry Biomass

Fresh biomass of harvested microgreens was recorded immediately after collection. Samples were then dried at 70–80°C until constant weight and reweighed to determine dry biomass. Moisture content was calculated using the difference between fresh and dry weights. (F. Bidarnamani,et.al.,2011)

Seed Germination Studies

Seed germination percentage was recorded after 48 h of incubation using the following equation:

Germination (%) = (Number of germinated seeds / Total number of seeds) × 100

(Bhattacharjee, A., & Ghosh, T. 2021).

Chlorophyll Estimation

Total chlorophyll content was estimated according to the acetone extraction method. Approximately 250 mg of fresh leaf tissue was homogenized in 80% acetone, centrifuged at

12,000 rpm for 10 min, and the absorbance of the supernatant was recorded at 646 and 663 nm using Schimadzu UV 1800 spectrophotometer. (Y. Zhang et.,al 2019)

Growth Parameters

Growth performance was assessed by recording the time required for green leaf emergence, number of leaves per plant, shoot length, root length, and leaf area index (LAI). Shoot and root lengths were measured using a graduated ruler, while LAI was calculated as the ratio of total leaf area to ground area occupied by the plant. (Y. Zhang,et.,2022)

The formula for Leaf Area Index (LAI) is:

$$LAI = \text{Leaf Area} / \text{Ground Area}$$

Seed Vigour Index

Seed vigour was determined according to the standard formula:

Seed Vigour Index (SVI) = Germination Percentage × Mean Seedling Length

Statistical Analysis

All experiments were performed in triplicate, and the results are expressed as mean ± standard deviation. Statistical significance among treatments should be evaluated using one-way analysis of variance (ANOVA), followed by an appropriate post hoc test, with differences considered significant at $p < 0.05$.

RESULTS AND DISCUSSION

Collection of*Eichhornia crassipes* Plant:-

The *Eichhornia crassipes*plants were procured from the lake near Porur, Chennai.

Extraction Yield and Physicochemical Characteristics of *Eichhornia crassipes* Polymer

The aqueous extraction of *Eichhornia crassipes* biomass yielded approximately 10% polymer on a dry weight basis. The extracted polymer appeared as a dark green, partially sheet-forming material after drying and exhibited a pH of 6.0, indicating a slightly acidic nature. The moderate extraction yield demonstrates the feasibility of recovering polymeric components from water hyacinth through a simple aqueous extraction process. The near-neutral pH is advantageous for hydroponic applications, as it is unlikely to adversely affect seed germination or early plant growth.

Biochemical Composition of *Vigna radiata*

The biochemical composition of *Vigna radiata* cultivated under different growth media is presented in Table 1. Plants grown in the *Eichhornia*-CMC hydrogel exhibited the highest carbohydrate (0.045 mg g^{-1}), protein (0.050 mg g^{-1}), and lipid (0.003 mg g^{-1}) contents compared with CMC hydrogel and soil. Although the differences were relatively small, the consistent increase suggests improved metabolic performance under the *Eichhornia*-based hydrogel. Enhanced carbohydrate accumulation may be associated with improved photosynthetic activity resulting from sustained moisture availability and efficient nutrient uptake, as the hydrogel acts as a moisture reservoir that maintains water availability in the root zone and supports continuous physiological activity. Similar improvements have been reported for cellulose-based hydrogels (Singh et al., 2021; Kumar et al., 2022). The higher protein and lipid contents may indicate improved nutrient assimilation and active cellular development, while the porous structure of the *Eichhornia*-CMC hydrogel may have enhanced root-zone aeration, nutrient diffusion, and metabolic activity. Naturally occurring bioactive compounds in *Eichhornia crassipes* may have further contributed to plant growth. Overall, the *Eichhornia*-CMC hydrogel provided a favourable root-zone environment and improved the biochemical composition of *Vigna radiata* compared with CMC hydrogel and soil, supporting its potential as a biodegradable and sustainable hydroponic substrate (Kumar et al., 2022).

Auxin Estimation

The endogenous auxin content of *Eichhornia crassipes* extract was quantified using the Salkowski colorimetric method and ranged from 4.2 to 4.6 µg mL^{-1} (Table 2), confirming the presence of naturally occurring auxin in the extracted polymer. Although the variation was minimal, its consistent detection suggests that *E. crassipes* biomass may possess plant growth-promoting potential in addition to its function as a biodegradable hydrogel matrix. Auxins regulate key developmental processes, including cell elongation, cell division, vascular differentiation, root initiation, and lateral root formation, thereby influencing water and nutrient uptake (Taiz et al., 2015; Davies, 2010). The detected auxin may therefore have contributed to the improved root and shoot growth, chlorophyll accumulation, and seedling vigour observed in *Vigna radiata*; however, as the present study measured total auxin concentration without establishing a direct causal relationship, these effects should be considered indicative rather than conclusive.

The improved growth response may further result from the combined effects of endogenous auxins and the moisture-retention capacity of the *Eichhornia*-CMC hydrogel. The hydrated microenvironment provided by the hydrogel may support nutrient diffusion and sustained physiological activity, while the gradual availability of bioactive compounds could promote seedling development. Previous studies have reported diverse bioactive constituents in *E. crassipes*, supporting its potential for agricultural valorization (Taiz et al., 2015; Davies, 2010).

Ash Content

The total ash content of *Vigna radiata* cultivated under different growth media is presented in Table 3. Plants grown in the *Eichhornia*-CMC hydrogel exhibited the highest ash content (3.65 g), followed by soil (3.55 g) and CMC hydrogel (3.50 g), indicating comparatively greater mineral accumulation under the *Eichhornia*-based treatment. Ash content serves as an indirect measure of the total inorganic mineral constituents in plant tissues, which are essential for enzyme activity, osmotic regulation, chlorophyll biosynthesis, and other physiological processes. The higher ash content may be attributed to the hydrogel's water-retention and porous structure, which can enhance nutrient solubilization, diffusion, and uptake within the root zone. In addition, the nutrient-rich nature of *Eichhornia crassipes* biomass may have contributed to mineral availability, although the elemental composition of the extracted polymer was not directly analysed. Improved mineral acquisition may also have supported the higher carbohydrate, protein, and chlorophyll contents observed in the present study (Ahmed, 2015). Similar improvements in nutrient availability and mineral uptake have been reported for biodegradable cellulose- and starch-based hydrogels (Fang et al., 2025; Sannino et al., 2022). (Iqbal et al., 2024; Saha et al., 2020). Overall, the findings suggest that *Eichhornia*-CMC hydrogel can improve mineral accumulation in *V. radiata* while providing a sustainable utilization pathway for invasive aquatic biomass.

Fresh Weight, Dry Weight and Water Content

The fresh weight, dry weight, and water content of *Vigna radiata* microgreens cultivated under different growth media are presented in Table 4. Plants grown in the *Eichhornia*-CMC hydrogel recorded the highest fresh weight (60 g), dry weight (4.0 g), and water content (53.33%), followed by soil (57 g, 3.7 g, and 50.50%, respectively) and CMC hydrogel (55 g, 3.5 g, and 48.63%, respectively). The higher fresh and dry biomass indicates improved plant growth, while the greater water content reflects the superior moisture-retention capacity of the *Eichhornia*-based hydrogel. Its three-dimensional polymeric network may have maintained continuous water availability in the root zone, thereby supporting cell expansion, nutrient transport, photosynthetic activity, and biomass accumulation. The higher dry weight further suggests that increased biomass was not solely due to water uptake but also reflected enhanced synthesis of organic matter, consistent with the higher carbohydrate, protein, and chlorophyll contents observed in the present study. Improved hydration may also have facilitated nutrient solubilization and uptake, contributing to sustained metabolic activity and vegetative development (Fang et al., 2025; Sannino et al., 2022). The fibrous and polysaccharide-rich nature of *Eichhornia crassipes* biomass may have further enhanced the swelling and water-holding properties of the hydrogel, creating a favourable root-zone environment. Similar improvements in plant biomass and moisture retention have been reported for cellulose-, starch-, and polysaccharide-based hydrogels (Fang et al., 2025; Sannino et al., 2022). Overall, the *Eichhornia*-CMC hydrogel improved biomass production and water retention in *V. radiata* compared with CMC hydrogel and soil, demonstrating its potential as a biodegradable and sustainable substrate for hydroponic cultivation and water-efficient agriculture.

Seed Germination

Seed germination is a critical stage determining seedling establishment and subsequent crop performance. As presented in Table 5, *Vigna radiata* seeds grown on the *Eichhornia*-CMC hydrogel and soil initiated germination on the first day, whereas those on CMC hydrogel germinated on the second day; however, all treatments achieved 100% germination (Table 6). The earlier emergence in the *Eichhornia*-based hydrogel may be associated with its superior water-retention capacity, which facilitates rapid imbibition and maintains stable moisture conditions required for enzyme activation, mobilization of stored reserves, and radicle emergence. The presence of endogenous auxin detected in the *Eichhornia* extract may have further contributed to early seedling development, although its direct role in germination was not established in the present study. The complete germination across all treatments also indicates that the *Eichhornia*-CMC hydrogel was compatible with *V. radiata* seeds and did not adversely affect seed viability.

Rapid and uniform germination can promote early root establishment, efficient resource utilization, and subsequent vegetative growth, potentially contributing to the higher shoot and root growth, chlorophyll content, biomass accumulation, and seed vigour observed in the *Eichhornia*-based treatment. Previous studies have demonstrated that biodegradable hydrogels enhance seed hydration, water availability, and seedling establishment under different growing conditions (Jong et al., 2025; Chirino et al., 2017). Although complete germination was achieved under the present controlled conditions, further evaluation under drought, salinity, and temperature stress would help establish the broader applicability of the hydrogel. Overall, the *Eichhornia*-CMC hydrogel supported rapid and complete germination of *V. radiata*, highlighting its potential as a biodegradable and sustainable substrate for hydroponic cultivation.

Chlorophyll Content

Chlorophyll content of *Vigna radiata* leaves cultivated under different growth media is presented in Table 7. Plants grown on the *Eichhornia*-CMC hydrogel exhibited the highest chlorophyll content (0.872 mg g^{-1}), followed by soil (0.869 mg g^{-1}) and CMC hydrogel (0.850 mg g^{-1}). Although the differences were relatively small, the higher chlorophyll content in the *Eichhornia*-based treatment suggests favourable physiological conditions for photosynthetic pigment accumulation. The improved response may be attributed to the hydrogel's water-retention capacity, which maintains moisture in the root zone and facilitates the uptake of essential nutrients such as nitrogen, magnesium, and iron required for chlorophyll biosynthesis. The higher biomass, carbohydrate and protein contents, mineral accumulation, and shoot and root growth observed in the same treatment further indicate enhanced metabolic activity. In addition, the endogenous auxins detected in the *Eichhornia* extract may have contributed indirectly to leaf development and chloroplast activity, although a direct relationship was not established. The comparable chlorophyll content between the *Eichhornia*-CMC hydrogel and soil demonstrates its ability to provide conditions suitable for maintaining photosynthetic activity without a conventional soil matrix. Similar improvements in chlorophyll accumulation have been reported for biodegradable cellulose- and polysaccharide-based hydrogels, which enhance water availability and nutrient-use efficiency. The higher chlorophyll content may consequently have contributed to the enhanced carbohydrate accumulation, biomass production, and seedling vigour observed in the present study. However, further studies involving chlorophyll fluorescence, gas exchange, photosynthetic rate, and stomatal conductance are required to confirm the underlying physiological mechanisms (Babaei, M., & Afkari, M. (2023)). Overall, the findings demonstrate that *Eichhornia*-CMC hydrogel can effectively support chlorophyll accumulation and plant physiological performance, highlighting its potential as a biodegradable and sustainable substrate for hydroponic cultivation.

Green Leaf Emergence and Leaf Production

Leaf emergence and production are important indicators of early vegetative development and plant vigour. As presented in Table 8, *Vigna radiata* grown on the *Eichhornia*-CMC hydrogel and soil produced green leaves on the fifth day, whereas CMC hydrogel showed delayed emergence on the seventh day. Plants grown on the *Eichhornia*-CMC hydrogel produced ten leaves per plant, comparable to soil but twice that of the CMC treatment (five leaves), indicating improved vegetative growth. The earlier leaf emergence and greater leaf production may be attributed to the hydrogel's water-retention capacity, which maintained adequate moisture and supported nutrient uptake, cell division, and leaf expansion. Endogenous auxins detected in the *Eichhornia crassipes* extract may have further contributed to shoot development and leaf initiation, although their direct role was not established. The enhanced leaf production was consistent with the higher chlorophyll content, biomass, carbohydrate and protein accumulation, and shoot growth observed in the *Eichhornia*-based treatment. Similar improvements have been reported for biodegradable cellulose- and polysaccharide-based hydrogels. Overall, the *Eichhornia*-CMC hydrogel promoted earlier leaf emergence and greater leaf production than CMC hydrogel and performed comparably to soil, supporting its potential as a sustainable hydroponic substrate.

Shoot and Root Length

Shoot and root lengths of *Vigna radiata* cultivated under different growth media are presented in Table 9. Plants grown on the *Eichhornia*-CMC hydrogel exhibited the highest shoot length (8.0–29.2 cm) and root length (3.0–9.0 cm), compared with CMC hydrogel (5.0–22.2 cm and 1.0–6.5 cm) and soil (7.0–28.8 cm and 2.8–8.2 cm), indicating improved vegetative growth under the *Eichhornia*-based treatment. The enhanced shoot and root elongation may be attributed to the hydrogel's favourable moisture-retention capacity and porous structure, which maintained adequate water availability, root-zone aeration, and nutrient diffusion. The presence of endogenous auxins detected in the *Eichhornia crassipes* extract may have further supported cell elongation and root development, although a direct causal relationship was not established. Improved root growth may also have contributed to the higher chlorophyll content, biomass, mineral accumulation, and seed vigour observed in the same treatment by facilitating efficient water and nutrient uptake. The comparable performance of the *Eichhornia*-CMC hydrogel with soil further demonstrates its potential as an alternative cultivation substrate. Overall, the findings indicate that *Eichhornia*-CMC hydrogel effectively promotes shoot and root development in *V. radiata*, supporting its application as a biodegradable and sustainable substrate for hydroponic and soilless cultivation.

Leaf Area index

Leaf area is an important indicator of vegetative growth and photosynthetic potential because greater leaf expansion enhances light interception, carbon assimilation, and biomass production (Taiz et al., 2018). As presented in Table 10, *Vigna radiata* grown on the *Eichhornia*-CMC hydrogel exhibited the highest leaf area (4.0 cm^2), followed by soil (3.5 cm^2) and CMC hydrogel (2.0 cm^2), indicating improved leaf expansion under the *Eichhornia*-based treatment. This response may be attributed to the hydrogel's water-retention capacity, which maintained adequate hydration and cell turgor while supporting nutrient uptake and leaf development (Ahmed, 2015; Montesano et al., 2015). The higher carbohydrate, protein, chlorophyll, and ash contents observed in the same treatment further suggest improved physiological activity and nutrient assimilation, particularly of minerals required for chloroplast development and photosynthesis (Marschner, 2012). The increased leaf area, together with higher chlorophyll content, biomass accumulation, and Seed Vigour Index, indicates enhanced photosynthetic and vegetative performance. In addition, the endogenous auxins detected in *Eichhornia crassipes* extract may have contributed to cell expansion and leaf development, although their direct role was not established (Davies, 2010; Zhao, 2010). Similar improvements have been reported for biodegradable polysaccharide-based hydrogels, which enhance water availability and nutrient-use efficiency (Ahmed, 2015; Montesano et al., 2015). Overall, the *Eichhornia*-CMC hydrogel promoted greater leaf expansion than CMC hydrogel and performed comparably to soil, supporting its potential as a sustainable substrate for hydroponic cultivation.

Seed Vigour Index (SVI)

The Seed Vigour Index (SVI), which integrates germination percentage and seedling growth, is an important indicator of seedling quality and establishment potential. As presented in Table 11, *Vigna radiata* grown on the *Eichhornia*-CMC hydrogel recorded the highest SVI (382), followed by soil (370), while CMC hydrogel showed the lowest value (287). Although all treatments achieved 100% germination, the higher SVI in the *Eichhornia*-based treatment was mainly associated with greater shoot and root development, indicating improved post-germination growth (Abdul-Baki & Anderson, 1973; Finch-Savage & Bassel, 2016). The enhanced vigour may be attributed to the hydrogel's water-retention capacity, which maintained continuous moisture availability and supported cellular expansion, nutrient transport, and metabolic activity (Ahmed, 2015; Montesano et al., 2015). Improved nutrient acquisition, reflected by higher carbohydrate, protein, chlorophyll, and mineral contents, may have further contributed to seedling development (Taiz et al., 2018). In addition, endogenous auxins detected in *Eichhornia crassipes* extract may have supported root initiation and cell elongation, although their direct role was not established (Davies, 2010; Zhao, 2010). The higher SVI was consistent with the improved shoot and root growth, leaf development, chlorophyll content, and biomass observed in the *Eichhornia*-CMC treatment. Overall, the findings demonstrate that *Eichhornia*-CMC hydrogel enhances seedling vigour compared with CMC hydrogel and performs comparably to soil, supporting its potential as a biodegradable and sustainable substrate for hydroponic cultivation.

Fig 1 *Eichhornia crassipes* plants in porur lake

Fig 2 Preparation of *Eichhornia crassipes* Polymer

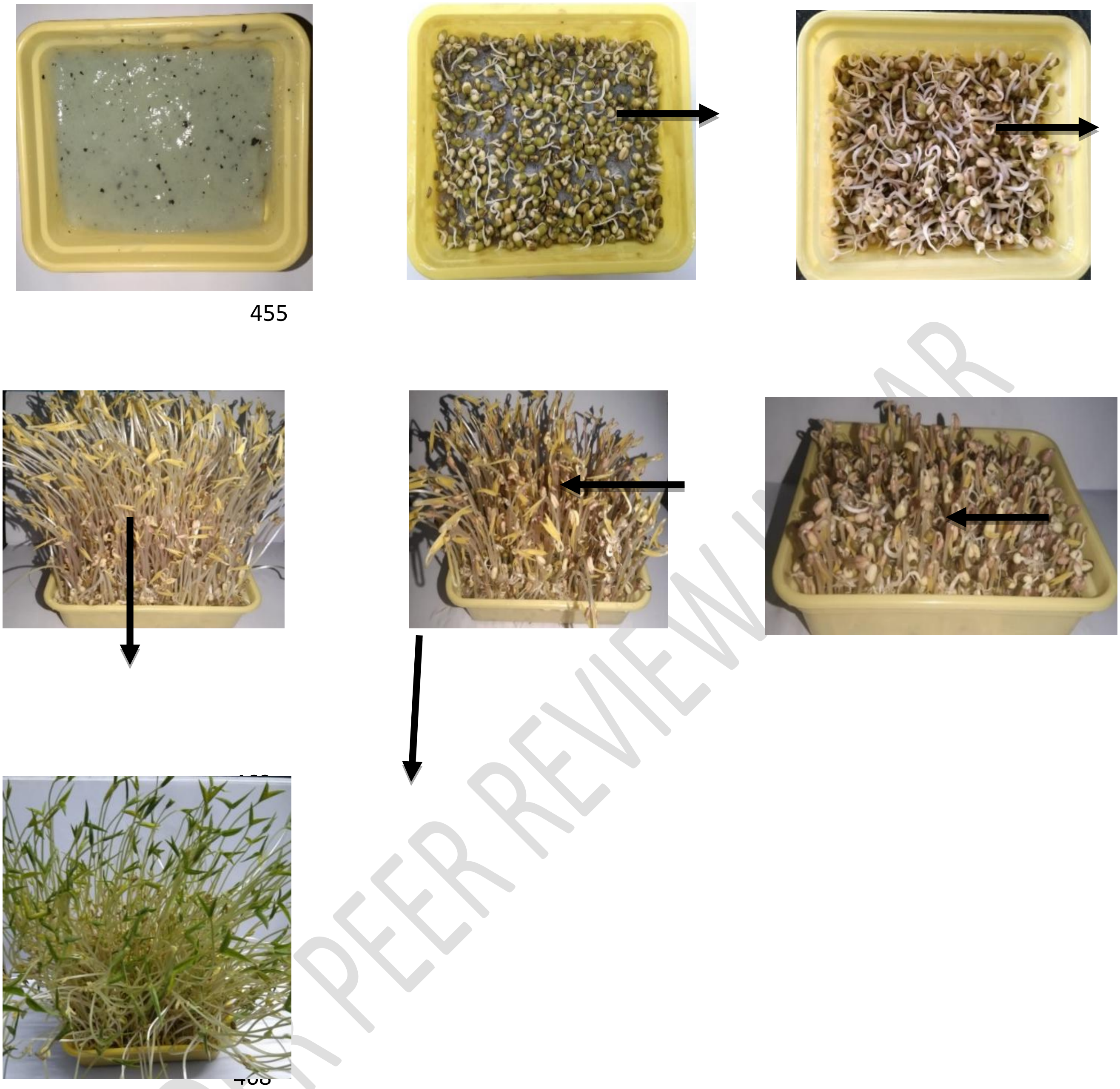

Fig 3Growing of *Vigna radiata L*. plant in of *Eichhornia crassipes*Hydrogel

Tests	Soil	CMC Hydrogel	Eichhornia Hydrogel
Carbohydrates	0.042mg/g	0.035mg/g	0.045mg/g
Protein	0.046mg/g	0.040mg/g	0.050mg/g
Lipids	0.002mg/g	0.001mg/g	0.003mg/g

Table 1 Quantitative analysis of phytochemicals present in*Vigna Radiata L.* plant extract

Test sample	Estimation of Auxin
Eichhornia plant Extract	4.2 µg/ml ±4.6 µg/ml

Table 2Estimation of Auxin by Salkowski method of *Eichhornia crassipes*plant.

Medium	Ash Content
Eichhornia Hydrogel	3.65 gms
CMC Hydrogel	3.50 gms
Soil	3.55 gms

Table 3 Determination of Ash Content in *Vigna Radiata L.*leaves.

Medium	Fresh weight	Dry weight	Water content
Eichhornia Hydrogel	60gms	4gms	53.33%
CMC Hydrogel	55gms	3.5gms	48.63%
Soil	57gms	3.7gms	50.50%

Table 4 Fresh Weight And Dry Weight of the *Vigna Radiata L.*Microgreens

Medium	Seed Germination Potential
Eichhornia Hydrogel	1^{st} Day
CMC Hydrogel	2^{nd} Day
Soil	1^{st} Day

Table 5 Seed Germination Potential

Medium	Germination Percentage
Eichhornia Hydrogel	100%
CMC Hydrogel	100%
Soil	100%

Table 6 The Germination Percentage Of *Vigna Radiata L.*Seed

Medium	Chlorophyll Content
Eichhornia Hydrogel	0.872 mg/g
CMC Hydrogel	0.850 mg/g
Soil	0.869 mg/g

Table 7 Chlorophyll Content of *Vigna Radiata L.*Leaves

Medium	Appearance of green leaves	Leaf Count
Eichhornia Hydrogel	5^{th} Day	10
CMC Hydrogel	7^{th} Day	5
Soil	5^{th} Day	10

Table 8 Appearance of Green Leaves and Leaf Count

Medium	Shoot Length	Root Length
Eichhornia Hydrogel	8cm ± 29.2cm	3cm ± 9cm
CMC Hydrogel	5cm ± 22.2cm	1cm ± 6.5cm
Soil	7cm ± 28.8cm	2.8 ± 8.2cm

Table 9 The Root and the Shoot Length of the *Vigna Radiata L.* Plant

Medium	Leaf Area Index
Eichhornia Hydrogel	$4cm^2$
CMC Hydrogel	$2cm^2$
Soil	$3.5cm^2$

Medium	Seed Vigour Index
Eichhornia Hydrogel	382
CMC Hydrogel	287
Soil	370

Table 10 Leaf Area Index(LAI)

Table 11Seed Vigour Index(SVI)

CONCLUSION

Hydroponic cultivation has emerged as a sustainable alternative to conventional agriculture by overcoming major constraints associated with soil-based farming, including soil degradation, excessive water consumption, nutrient depletion, and the increasing demand for arable land. The development of environmentally friendly and cost-effective hydroponic substrates is therefore essential for expanding the adoption of soilless cultivation systems.

The present study demonstrated the successful utilization of *Eichhornia crassipes* biomass as a biodegradable hydrogel substrate for hydroponic cultivation of *Vigna radiata* L. An aqueous extraction process yielded approximately 10% polymer with a slightly acidic pH (6.0), which was subsequently incorporated with carboxymethyl cellulose (CMC) to formulate a stable hydrogel. The performance of the *Eichhornia*-CMC hydrogel was systematically compared with CMC hydrogel and conventional soil under identical growth conditions.

The results clearly indicated that the *Eichhornia*-CMC hydrogel significantly enhanced several growth and physiological parameters of *Vigna radiata*. Plants cultivated on the hydrogel exhibited superior seedling vigour, greater shoot and root elongation, increased leaf area, higher chlorophyll content, improved water retention, enhanced mineral accumulation, and increased nutritional quality, including carbohydrate, protein, and lipid contents. The hydrogel also supported rapid seed germination and promoted early vegetative development, demonstrating its suitability as an efficient hydroponic growing medium. Furthermore, the measurable auxin content in *Eichhornia* biomass may have contributed to the improved plant growth observed during cultivation.

Beyond its agronomic performance, the study highlights an environmentally sustainable strategy for converting the invasive aquatic weed *Eichhornia crassipes* into a value-added agricultural resource. Utilization of water hyacinth biomass not only reduces the environmental burden associated with its uncontrolled proliferation but also promotes biomass valorization, waste minimization, and circular bioeconomy principles. The replacement of commercially available hydroponic substrates with renewable plant-derived hydrogels has the potential to reduce production costs while improving the sustainability of hydroponic farming.

Although the present investigation focused on mung bean as a model crop under laboratory-scale conditions, further research should evaluate the long-term stability, mechanical properties, biodegradation behaviour, nutrient-release kinetics, microbial interactions, and economic feasibility of the hydrogel under greenhouse and commercial cultivation systems. Validation across diverse horticultural crops and optimization of hydrogel formulations will further establish its practical applicability.

Overall, the findings demonstrate that the *Eichhornia*-CMC hydrogel represents a promising, biodegradable, and sustainable alternative to conventional hydroponic substrates. By integrating invasive biomass utilization with soilless cultivation technology, this study contributes to sustainable agriculture, environmental conservation, and resource-efficient food production. The proposed hydrogel offers considerable potential for future hydroponic applications and supports the transition toward climate-resilient and circular agricultural systems.

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