

Optimising Irrigation Intervals in Hydrogel-Amended Media: Effects on Growth Yield, and Physiological Responses of Chilli (*Capsicum annum* L.)

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ABSTRACT

This study investigates the effects of superabsorbent biodegradable hydrogel-amended planting media on *Capsicum annum* L. under different irrigation intervals. A randomised complete block design (RCBD) was employed with five irrigation treatments (T1–T5), ranging from daily to six-day intervals. Morphological traits, yield attributes, dry matter partitioning, leaf gas exchange, and cell membrane stability were evaluated. Results indicate that a one-day irrigation interval (T2) with hydrogel-amended media significantly improved plant height (126.9 cm), fruit yield (981.53 g), and dry biomass compared to longer irrigation intervals. Additionally, hydrogel integration influenced leaf gas exchange responses and contributed to maintaining cell membrane stability, as reflected in lower relative injury (RI) values under prolonged irrigation intervals. These findings provide insights into optimising irrigation scheduling and hydrogel application to sustain chilli plant performance under different irrigation regimes.

1 INTRODUCTION

Chilli (*Capsicum annum* L.) is a globally significant horticultural crop cultivated for its culinary, industrial, and medicinal uses. Chilli, a member of the Solanaceae family that also includes tomatoes, potatoes, and eggplants, is widely grown due to its economic value and nutritional benefits. In 2020, global

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chilli production was estimated to exceed 36.14 million metric tons, placing it among the top ten most cultivated vegetables worldwide¹. Recent data from 2024 indicate that chilli production has surpassed 40 million metric tons, reflecting its growing demand in various industries, including food processing and pharmaceuticals².

Despite its economic significance, chilli production is highly sensitive to environmental factors, particularly temperature and water availability. Optimal growth occurs within a temperature range of 20–30 °C, however, in many tropical regions, temperatures frequently exceed this threshold, leading to heat and drought stress conditions. Studies have shown that temperatures above 30 °C negatively impact photosynthesis, nutrient uptake, root development, and fruit set, ultimately reducing crop yield and quality³. Moreover, prolonged exposure to heat stress can exacerbate water loss through transpiration, making water availability a critical factor in sustaining chilli cultivation under tropical and semi-arid conditions⁴.

Water stress, caused by limited water availability or inefficient irrigation management, is one of the most significant abiotic factors affecting plant growth and productivity. An insufficient water supply disrupts cellular metabolism, enzymatic activities, and nutrient uptake, leading to reduced photosynthetic efficiency, chlorophyll degradation, and impaired fruit development. Under severe drought conditions, chilli plants exhibit symptoms such as leaf wilting, stomatal closure, and reduced transpiration rates, which collectively limit biomass accumulation and fruit yield⁵. Given the increasing unpredictability of rainfall patterns and growing concerns over water scarcity, the development of water-efficient irrigation strategies is crucial for maintaining sustainable chilli production in water-limited environments⁶.

One promising solution to mitigate water stress in chilli cultivation is the integration of superabsorbent hydrogels into planting media. Hydrogels are cross-linked polymer networks capable of absorbing and retaining large quantities of water, which they gradually release to plant roots over time, ensuring sustained moisture availability⁷. The biodegradable nature of modern hydrogels enables them to improve soil structure without posing long-term environmental concerns⁸. Several studies have demonstrated that hydrogel applications can significantly enhance soil moisture retention, nutrient delivery, and overall plant growth performance under drought conditions⁹. Recent research has also highlighted the role of poly(vinyl pyrrolidone)-based superabsorbent hydrogels in enhancing root hydration and increasing crop resilience to prolonged water scarcity¹⁰.

Hydrogels function by reducing water loss through evaporation and leaching, thereby ensuring more efficient use of irrigation water. Furthermore, they help stabilize soil pH, improve aeration, and enhance nutrient bioavailability, which collectively contribute to improved plant health and productivity¹¹. Studies on various crops, including legumes and leafy vegetables, have shown that hydrogel-treated soils exhibit improved water retention of up to 73%, leading to enhanced biomass production¹². However, limited research has examined the effects of hydrogel integration with different irrigation intervals in controlled fertigation systems, particularly for high-value crops like chilli.

Given the increasing global demand for water-efficient agricultural practices, there is an urgent need to evaluate alternative irrigation strategies that optimise water retention while sustaining high crop yields. While hydrogel amendments have been extensively studied in open-field agriculture, their effectiveness in soilless and controlled fertigation systems remain insufficiently explored. Therefore, this study aims to assess the impact of different irrigation intervals in hydrogel-amended planting media on the morphological, physiological, and yield attributes, as well as dry matter partitioning and cell membrane stability of *Capsicum annuum* L.

2 MATERIALS AND METHODS

2.1 Experiment site

The experiment was conducted under glasshouse conditions at the Institute of Tropical Agricultural and Food Security (ITAFoS), Universiti Putra Malaysia, Serdang. All treatments were replicated across controlled environments during the cultivation period to ensure data consistency. Standard agronomic practices and uniform climatic conditions (average 25–33 °C, 75% RH, and 4.55 mm daily rainfall) were maintained throughout the study. Data were analysed collectively to enhance statistical power and treatment representation.

2.2 Plant materials and culture conditions

Chilli seeds used in this study were sown in seed trays (9 × 12 cells) filled with peat moss in a nursery at the experimental site. Seedlings sprouted within 3–10 days and were transplanted into 25 × 25 cm polybags four weeks after sowing. The polybags were prepared in advance and positioned from east to west, spaced at 75 × 50 cm intervals, based on the plant rooting zone and structure robustness, to avoid competition for light and space under glasshouse conditions. The glasshouse was utilised to protect the plants from heavy rainfall and leaf wetness.

The current study employed a fertigation system for irrigation and fertilisation purposes due to its water-saving capabilities. The approach followed the guidelines in the first edition of the Malaysian Agricultural Research and Development Institute (MARDI) Fertigation System Manual. The plants were treated with Solomon, Confidor, and Dimet 40 pesticides once or twice weekly, while the fungicide Kencozeb (Kenso, Australia) was sprayed as needed to maintain plant health.

The plants in the study were subjected to five treatments: T1 = daily, T2 = two-day, T3 = three-day, T4 = four-day, and T5 = six-day irrigation intervals with five replications respectively. Approximately 1.5 kg of saturated hydrogel was embedded at a depth of 8–15 cm within the cocopeat-filled polybags. This hydrogel-amended media¹³ ensured the same amount of nutrient throughout the study. The micro and macronutrient components of the 30 L fertiliser stock solution which was recommended by MARDI¹⁴, are listed in Table .

Table 1. The micro and macro components in the fertiliser stock solution

Component	Weight (g)
Solution A	
Calcium nitrate	11,500
Iron	190
Solution B	
Potassium nitrate	600
Magnesium sulphate	4,030
Monopotassium phosphate	2,220
Mangan	7
Boron	33
Copper	2
Zinc	15
Ammonium molybdate	2

2.3 Data collection

Data on the morphological characteristics of the plants, including height (cm), stem girth (cm), number of fruits, leaves, and branches, and the weight of fresh fruit (g), dry root (g), and dry shoot (g), were collected during the study. The physiological traits were also determined, such as photosynthesis rate,

stomatal conductance, intercellular carbon dioxide (CO₂) concentration, transpiration rate, and cell membrane thermostability.

Plant height was measured from the surface of the planting media to the tip of the plant using a measuring tape. Stem girth was determined with a vernier calliper. Fruits were harvested every three days and individual fruits were weighed and were referred as the fresh fruit weight. The total number of fruits harvested per plant represented the number of fruits. Chilli fruits were harvested once they turned from green to red or 120 days after transplant (DAT).

Leaf gaseous exchange responses, such as photosynthesis rate, stomatal conductance, CO₂ concentration, and transpiration rate, were observed at the flowering stage. Five plant samples from each treatment were collected after an hour of watering between 0900 and 1100 hours, to ensure light conditions provided the maximum photosynthetic rates. The assessment was performed with a Li-6400XT infrared gas analyser [Li-cor Inc., Lincoln, Nebraska, United States of America (USA)] on the expanded third or fourth leaves.

2.4 Cell membrane stability

The cell membrane stability (CMS) or thermostability test was conducted according to the protocol described by Martineau et al.¹⁵. Firstly, samples from the tip of the fully expanded third or fourth leaves of plants from each treatment were cut into six 1 cm² discs. The samples were prepared in three replicates in pairs, control (C) and treatment (T), and each sample type was placed in a test tube containing distilled water. Subsequently, the discs were washed thoroughly four times with 20 mL of distilled water to remove any surface electrolytes. Excess water was then drained, and the discs were left in their respective tubes with residual water adhering to the leaves.

The treatment test tube was capped and placed in a water bath at 50 °C, while the control test tube was maintained at 25 °C for 15 minutes. After the treatment, the test tube was cooled, and the control and treatment test tubes were filled with 30 mL of distilled water. The tubes were then incubated in a refrigerator at 4 °C for 18 hours to allow electrolytes to diffuse from the discs. Subsequently, the tubes were brought to room temperature, and the contents were mixed by inverting the tubes several times. The initial conductance readings (CEC1 and TEC1) were then measured with an electrical conductivity meter (Hanna HI 8733).

The control and treatment tubes were covered and autoclaved at 121 °C for 20 minutes to kill the leaf tissues completely. Subsequently, both tubes were cooled to room temperature and mixed thoroughly for the final conductance reading, CEC2 and TEC2. The CMS and relative injury (RI) percentages were calculated based on Equations 1 and 2.

$$\text{CMS (\%)} = \left[\frac{1 - (\text{TEC1}/\text{TEC2})}{1 - (\text{CEC1}/\text{CEC2})} \right] \times 100 \quad (1)$$

$$\text{RI (\%)} = \left[1 - \frac{1 - (\text{TEC1}/\text{TEC2})}{1 - (\text{CEC1}/\text{CEC2})} \right] \times 100 \quad (2)$$

2.5 Experimental design and statistical analysis

The experiment followed a randomised complete block design (RCBD) with five irrigation interval treatments (T1–T5) and five replications per treatment. All data were collected under uniform glasshouse conditions with consistent treatment application throughout the cultivation period. The dataset was analysed collectively to enhance statistical representation and account for treatment performance across repeated, but comparable, growing conditions. One-way analysis of variance (ANOVA) was performed using R Studio, and treatment means were compared using the Least Significant Difference (LSD) test at a 5% significance level ($p \leq 0.05$).

3 RESULTS

3.1 Growth measurement

The irrigation interval had a statistically significant effect on most morphological parameters, including plant height, stem girth, number of leaves, and branches (Table 2). Notably, plants under T2 (one-day interval with hydrogel) recorded a comparable performance to the control (T1) in terms of height and vegetative structure, suggesting that hydrogel effectively compensated for the reduced irrigation frequency. In contrast, plants under T5 (a six-day interval) exhibited significantly lower morphological growth, underscoring the threshold limit of hydrogel water release capacity in extended dry intervals (Table 3). These observations confirm that hydrogel-amended media can sustain growth performance under moderate irrigation reduction.

Table 2. The analysis of variance for morphological traits of chilli under different irrigation intervals in the hydrogel planting medium

SOV	DF	PH	SG	Brix	LN	NB
Replication	4	183.5	2.55	1.75	715	84.93**
Irrigation Interval	4	3695.4***	61.239***	0.5	38389***	110.18***
Error	41	189.4	1.538	0.82	5417	28.66

Note: Significance codes: *** denotes 0, ** represents 0.001, * is 0.01; the means followed by similar letters within the column for each parameter were not significantly different at $p \leq 0.05$ based on the LSD multiple mean comparisons

Table 3. The mean comparison for morphological traits of chilli under different irrigation intervals

Irrigation Interval (I)	PH (cm)	SG (cm)	Brix	LN	NB
T1	133.5 ^a	14.5 ^a	6.00 ^a	283.1 ^b	19.0 ^a
T2	126.9 ^a	13.2 ^b	5.70 ^a	359.7 ^a	18.4 ^a
T3	110.8 ^b	10.1 ^c	5.85 ^a	274.6 ^b	16.6 ^{ab}
T4	99.4 ^b	9.6 ^{cd}	5.80 ^a	241.5 ^{bc}	13.5 ^{bc}
T5	86.8 ^c	8.8 ^d	5.40 ^a	190.6 ^c	11.2 ^c
Mean	111.50	11.50	5.75	269.90	15.70

Note: T1 = control, T2 = one-day, T3- two-day, T4 = three-day, and T5 = six-day irrigation intervals; PH = plant height, SG = stem girth, LN = Leave's number, NB = number of branches

3.2 Yield attributes and dry matter partitioning

Irrigation interval also significantly affected the yield attributes, including the number of fruits (FN) and fresh weight (FW) (Fig. 1), as well as dry matter partitioning, which includes root dry weight (RDW) and shoot dry weight (SDW) in chilli plants (Table 4). The plants subjected to the one-day irrigation interval demonstrated notably higher yield attributes, 21–30%, compared to the controls planted in the cocopeat medium with daily irrigation. Conversely, the six-day irrigation interval samples recorded the lowest yield attributes and documented a significant reduction (66–71%) compared to the control (Table 5).

Table 4. The analysis of variance for yield attributes and dry matter partitioning of chilli responses under different irrigation intervals in the hydrogel planting medium.

SOV	DF	FN	FW	RDW	SDW
Rep	4	15.6	10207	9.96	210.4
Irrigation Interval	4	4874.9***	784015***	1463.99***	26386.4***
Error	36	98.2	16051	29.28	276.9

Note: Significance codes: *** denotes 0, ** represents 0.001, * is 0.01; SOV: source of variation; DF: degrees of freedom; FN = Fruit's number; RDW = Root dry weight; SDW = Shoot dry weight

The plants exposed to frequent irrigation, T1 (daily) and T2 (two-day interval), also demonstrated the highest root and shoot dry weight partition compared to those with less frequent irrigation intervals (T3, T4, and T5) (Table 5).

Table 5. The yield attributes and dry matter partitioning of chilli responses under different irrigation intervals in the hydrogel planting medium

Irrigation Interval	FN	FW	RDW	SDW
T1	57.9 ^b	730.25 ^b	31.82 ^a	119.84 ^b
T2	77.3 ^a	981.53 ^a	35.59 ^a	164.83 ^a
T3	46.6 ^c	585.34 ^c	19.46 ^b	74.81 ^c
T4	38.4 ^c	483.91 ^c	11.74 ^c	55.79 ^d
T5	18 ^d	229.31 ^d	8.03 ^c	38.36 ^e
Mean	47.60	602.07	21.33	90.73

Note: The means followed by similar letters within the column for each parameter were not significantly different at $p \leq 0.05$ based on the LSD multiple mean comparisons. FN = Fruit's number; RDW = Root dry weight, SDW = Shoot dry weight



Fig. 1. The effect of different irrigation treatments on fruits in the hydrogel planting medium.

3.3 The leaf gaseous exchange

The physiological responses, including photosynthesis rate, stomatal conductance, intercellular CO₂ concentration, and transpiration, were not significantly affected by irrigation interval, as indicated by ANOVA results (Table 6). However, descriptive trends presented in Fig. 2 indicate that T1 (daily irrigation) and T2 (one-day interval) consistently exhibited slightly higher mean values across all physiological parameters, suggesting better gas exchange performance under more frequent irrigation. In contrast, T5 (six-day interval) showed a noticeable decline in photosynthetic and transpiration rates. While these differences were not statistically significant, the consistent patterns align with the observed reductions in growth and yield parameters, further supporting the role of hydrogel in sustaining physiological function under moderate irrigation frequency.

Table 6. The analysis of variance for the physiological responses of chilli in different irrigation intervals in the hydrogel planting medium

SOV	DF	SPAD	Photo	Stomata	CO ₂	Trans
Replication	4	70.41	144.36***	0.25***	1127.11*	51.52***
Irrigation Interval	4	333.79***	9.9	0.03	166.77	4.46
Error	41	56.68	9.919	0.03	342.89	6.94

Note: Significance codes: *** denotes 0, ** represents 0.001, * is 0.01, SOV: source of variation; DF: degrees of freedom. Photo = photosynthesis rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$), Stomata = stomatal conductance ($\mu\text{mol m}^{-2} \text{s}^{-1}$), CO₂ = intercellular CO₂ concentration ($\mu\text{mol m}^{-1}$), Trans = transpiration rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$) of the chilli plants at DAT120

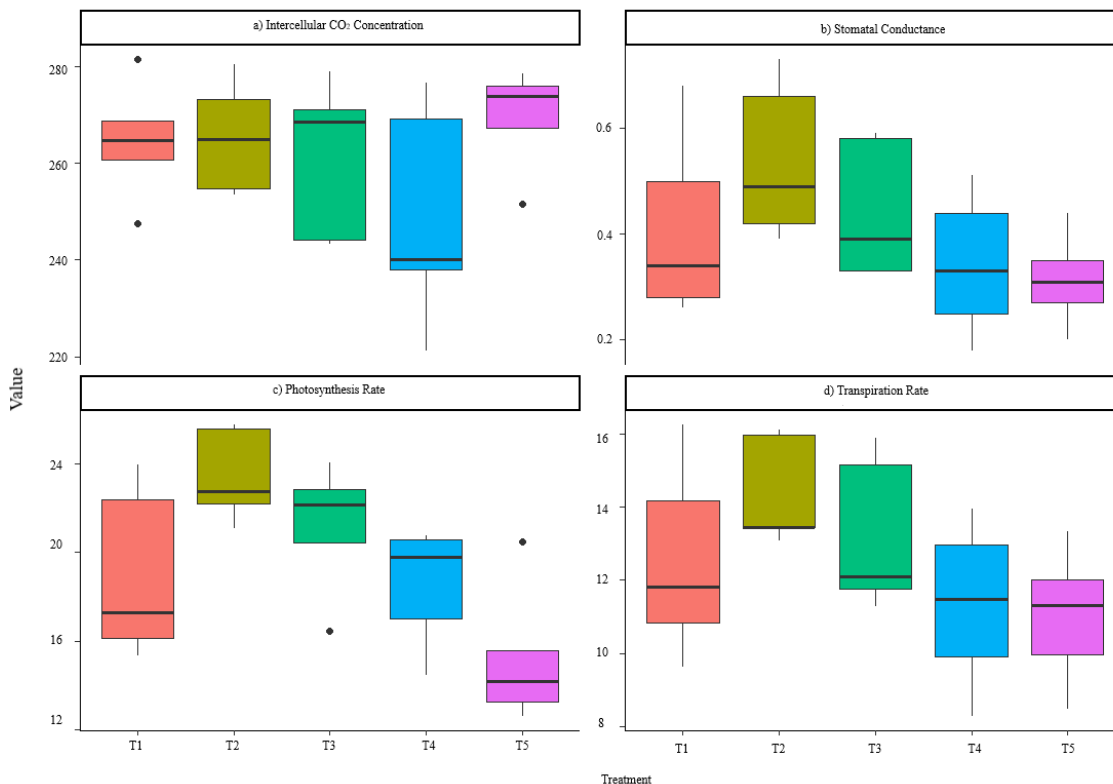


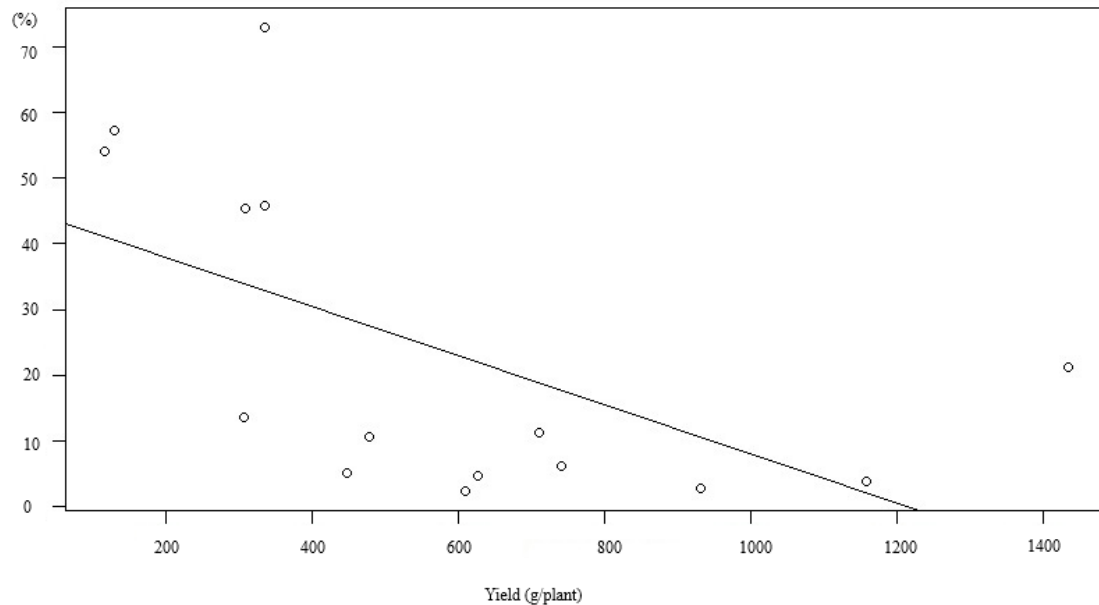
Fig. 2. The effects of different irrigation interval treatments on the (a) intercellular CO₂ concentration ($\mu\text{mol m}^{-1}$), (b) stomatal conductance ($\mu\text{mol m}^{-2} \text{s}^{-1}$), (c) photosynthesis rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$), and (d) transpiration rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$) of the chilli plants at DAT120.

3.4 The cell membrane stability (CMS)

CMS values were significantly higher in T1, T2, and T3 (88.09%, 88.27%, and 87.83% respectively), indicating greater membrane stability in plants under daily and one to two-day irrigation intervals. In contrast, CMS declined sharply in T4 (57.64%) and T5 (54.45%) with RI values increasing to 42.36% and 45.54% respectively. These results suggest that plants subjected to prolonged irrigation intervals experience increased membrane injury (Table 7). A significant negative correlation ($r = -0.51$) was observed between RI and fruit yield, as shown in Fig. 3, indicating that as membrane injury increases, yield performance declines.

Table 7. Mean CMS and RI (%)

Irrigation Interval (I)	CMS (%)	RI (%)
T1- Control- Everyday irrigation	88.09 ^a	11.91 ^b
T2- One-day irrigation interval	88.27 ^a	11.73 ^b
T3- Two-days irrigation interval	87.83 ^a	12.16 ^b
T4- Three- days irrigation interval	57.64 ^b	42.36 ^a
T5- Six- days irrigation interval	54.45 ^b	45.54 ^a

Fig. 3. The RI (%) on the yield of fresh chilli fruit weight with $R^2 = 0.26$.

4 DISCUSSION

The present study evaluated the influence of irrigation scheduling in hydrogel-amended soilless media on the growth, physiological response, and productivity of *Capsicum annuum* L. grown under a controlled fertigation system. The findings clearly demonstrated that the hydrogel-supported planting media, especially under the one-day irrigation interval (T2), sustained chilli plant development without compromising growth or yield. These outcomes were consistently observed under repeated growing conditions with uniform management practices and environmental settings, allowing a reliable evaluation of hydrogel performance in a controlled environment.

The morphological traits, such as plant height, stem diameter, and number of leaves and branches were significantly influenced by irrigation frequency ($p \leq 0.05$). While the daily irrigation control (T1) served as a baseline, the T2 treatment achieved statistically comparable outcomes indicating that hydrogel supplementation can compensate for reduced irrigation frequency while maintaining optimal physiological activity. These results highlighted the potential of hydrogels to moderate water stress and support vegetative growth under reduced irrigation regimes. In contrast, the T5 treatment (six-day interval), consistently showed reduced growth, confirming that the water-holding capacity of the hydrogel is insufficient to fully support plant demands under prolonged drought stress.

The decline in cell membrane stability (CMS) and the corresponding increase in relative injury (RI) observed in T4 and T5 treatments confirmed that prolonged irrigation intervals impose physiological stress on chilli plants. Conversely, the consistently high CMS values (above 87%) recorded in T1 to T3 indicated greater membrane integrity, which likely contributed to sustained growth and yield under reduced irrigation. These results suggested that hydrogel amendment in the growing media effectively mitigated the effects of moderate water stress by retaining sufficient moisture to maintain cellular function. Furthermore, the significant negative correlation ($r = -0.51$) between RI and fruit yield (Fig. 3) highlighted the relevance of membrane injury as a physiological indicator of drought impact. These findings were consistent with previous reports that electrolyte leakage serves as a sensitive marker of abiotic stress tolerance^{15–17} and that membrane stability plays a key role in protecting cellular homeostasis under limited water availability¹⁸.

The current findings supported earlier reports, suggesting that hydrogel application can improve the physicochemical properties, water retention capacity (by up to 73%¹²) of the planting medium, thereby enhancing water-use efficiency. Moreover, the field capacity and wilting point of the planting medium could be influenced by irrigation intervals¹⁹. In the current study, the plants exposed to longer fertigation intervals recorded the lowest results in all growth parameters, which was possibly due to declining cell enlargement and division.

The irrigation intervals of the hydrogel amended treatment significantly affected dry matter partitioning in the present study. The nitrogen (N) uptake, vegetative growth, and biomass production of plants exposed to water stress were considerably reduced, hence resulted in reduced root growth, overall biomass, and apical structures²⁰. Previous investigations suggested that applying hydrogel could maximise planting media dynamics¹², resulting in higher dry partitioning of shoots, roots, and total leaf area. Plants start producing flowers and fruits in the generative stage, and the dry matter allocation prioritises the reproductive organs (flowers and fruits) over the roots during this phase. The results in the current study were in line with previous literature that stated that exposure to longer fertigation intervals diminished the root dry matter partitioning in plants.

Cultivating chilli in bigger polybags did not affect the physiological responses of the plants²¹. In the present study, physiological measurements related to gas exchange, namely photosynthesis rate, stomatal conductance, transpiration, and intercellular CO₂ concentration, were recorded at the flowering stage (DAT120). This time point was selected based on the physiological stability of the plants and the need to capture data under peak photosynthetic activity, which typically aligned with the transition to the reproductive phase. Although measurements during the vegetative stage might have offered earlier insights into stress response onset, the flowering stage offers a more integrated snapshot of cumulative plant performance. Nonetheless, the absence of data from earlier developmental phases is acknowledged as a limitation, and future studies are recommended to incorporate multi-stage physiological assessments to better capture the dynamic effects of irrigation scheduling.

The observations might be attributed to the bound and half-bound water in the swollen hydrogel containing hydrophilic groups ($-\text{CO}_2\text{H}$ and $-\text{CO}_2\text{Na}$), that enabled the planting medium to retain moisture even in deficit irrigation²². Consequently, the incorporation of hydrogels supported plant growth, improved photosynthetic activities, and increased transpiration rate, hence influencing the translocation of photosynthates toward sinking organs. Furthermore, the findings were consistent with previous literature showing that hydrogels enhanced nutrient availability in frequent fertigation and increased yield attributes. Although statistical differences were not observed in the gas exchange parameters, consistent numerical trends across treatments suggested potential biological relevance. This warrants further investigation using larger sample sizes or under conditions of heightened water stress to determine whether these physiological trends reflect meaningful treatment effects.

The CMS indicated normal cellular functionalities of plants under drought conditions. Plants with higher CMS values tended to perform better in drought environments, thus lowering RI. Nevertheless,

thermal stress can impair the membrane functions of cells due to electrolyte leakage. Electrolyte leakages were measured by RI, representing membrane stability damages due to drought stress. The current study demonstrated that frequent fertigation produced superior CMS and lowered RI regardless of the planting medium. Nonetheless, the plants treated with daily to six-day fertigation intervals did not demonstrate wilting symptoms, presumably due to potassium ions (K^+) playing a critical role in the osmotic adjustment of the plants.

Water stress is closely associated with heat stress, both of which can impair cell membranes and lead to injuries¹⁷. The findings are in line with the previous findings of yield reductions in wheat and rice breads under prolonged heat stress^{23,24}. Nevertheless, in the current study, trial plants exposed to water stress did not exhibit wilting symptoms, likely due to the osmotic adjustment mechanisms that enable plants to survive prolonged water scarcity²⁵.

The findings from this study have direct implications for irrigation management and water-use efficiency in high-value horticultural crops such as chilli. The integration of superabsorbent hydrogels into soilless media provides a practical strategy to sustain plant growth under reduced irrigation frequency, without compromising yield. This is particularly relevant in regions facing increasing water scarcity, where growers must optimise resource use while maintaining productivity. The significant reduction in RI and maintenance of CMS under moderate fertigation intervals highlight the physiological resilience imparted by hydrogel amendments. These insights support the wider adoption of hydrogel-enhanced fertigation systems as a water-saving strategy, especially in controlled environment agriculture or urban farming settings. Further investigation into long-term performance, economic viability, and interactions with diverse nutrient formulations will strengthen the application of these findings in commercial practices.

5 CONCLUSION

The application of hydrogel-amended planting medium with a one-day fertigation interval resulted in notable improvements in numerous attributes of the chilli plants in the present study. The plants under the most extended fertigation interval (six days) did not exhibit visible wilting symptoms during the experiment. Conventionally, the composition of a planting medium determines its ability to retain water, where larger particles possess reduced water-keeping ability. Consequently, incorporating hydrogel into fertigation may help growers conserve water and reduce labour costs while maintaining or increasing yield due to its high surface area, biocompatibility, and excellent moisture absorption properties. Nevertheless, further studies should be conducted to assess the interaction between hydrogel treatment and other chilli genotypes. Additionally, optimising hydrogel application rates is essential to determine the most effective and most economical hydrogel utilisation.

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CONFLICT OF INTEREST

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

Conceptualisation: S. S. Sahmat
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 Supervision: M. R. Yusop
 Funding acquisition: M. R. Yusop
 Project administration: M. R. Yusop

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