



A Comparative Study of Microclimate and Vegetative Growth of Land Spinach (*Ipomoea aquatica*) and Red Chili (*Capsicum annuum*) in Open and Closed Terrarium Models

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ABSTRACT

Microclimate conditions play an important role in regulating plant growth, physiological processes, and morphological development. This study aimed to compare the effects of open and closed terrarium models on the microclimate and vegetative growth of land spinach (*Ipomoea aquatica*) and red chili (*Capsicum annuum*). A true experimental design using quantitative and qualitative comparative approaches was conducted over three weeks, from May 29 to June 12, 2026, at Universitas HKBP Nommensen Pematangsiantar, North Sumatra, Indonesia. Two terrarium models with different air circulation conditions were established using identical containers, growing media, and planting configurations. Microclimate parameters, including temperature and relative humidity, were monitored, while plant growth was assessed weekly by measuring stem height and observing leaf color, stem strength, and morphological abnormalities. The results revealed substantial differences between the two models. The open terrarium maintained temperatures of 23.5–27.0°C and relative humidity of approximately 65%, supporting proportional growth, sturdy stems, and healthy green leaves in both plant species. In contrast, the closed terrarium maintained temperatures of 24.0–25.5°C and extreme relative humidity of 96–99%. Under these conditions, land spinach exhibited excessive stem elongation, with one specimen reaching 35 cm and a relative growth rate (RGR) of 6.75 cm/week, accompanied by bending and competition for light and space. Meanwhile, red chili growth slowed considerably, with the lowest recorded RGR of 0.90 cm/week, alongside weak stems and leaf chlorosis. These findings demonstrate that restricted air circulation and excessive humidity produce species-specific growth responses. Although the closed terrarium stimulated rapid stem elongation in land spinach, it compromised plant structure and negatively affected red chili development. In conclusion, open terrarium systems with adequate air circulation provide more favorable conditions for healthy vegetative growth, particularly for red chili. Future research should incorporate ventilation control and additional physiological measurements to improve understanding of plant responses to microclimatic variation.

Keywords: *Chlorosis; Etiolation; Microclimate; Terrarium; Vegetative Growth*

Introduction

A terrarium is a micro-scale artificial biosphere that replicates the fundamental thermodynamic and hydrological mechanisms of terrestrial ecosystems within transparent containers (Djeppu & Ariawan, 2023; Smith & Jones, 2025). In ecological modeling and indoor agricultural studies, terrarium architectures are primarily classified into two physical models: open terrarium and closed terrarium systems (Amini et al., 2023; Djeppu & Ariawan, 2023; Sari et al., 2023). These two mechanical designs induce contrasting microclimatic regimes, particularly regarding

fluctuations in ambient air temperature, vapor pressure deficit (VPD), relative air humidity (RH), solar radiation transmittance, and substrate water retention capacity (Zhang et al., 2024). A precise understanding of microclimatic dynamics within controlled artificial habitats is scientifically paramount, as atmospheric humidity and air circulation serve as critical environmental limiting factors that directly dictate internal physiological processes in plants, including stomatal conductance, photosynthetic efficiency, transpirational pull, and root-zone ion absorption dynamics (Hidayat & Pratama, 2022; Kumar et al., 2025; Liu et al., 2022).

In closed terrarium systems, the physical barrier against mass and gas exchange with the ambient atmosphere drives the formation of a self-sustaining, isolated micro-hydrological cycle (Chen et al., 2023; Djeppu & Ariawan, 2023; Soil Ninja, 2024). Water vapor generated via substrate evaporation and foliar transpiration accumulates within the confined interior, condenses upon reaching the cool glass interface, and precipitates back into the growing medium (Gomez et al., 2022; Hesi, 2026). While this enclosed loop supports humidity-loving shade vegetation, it frequently subjects fast-growing crops to continuous atmospheric saturation (RH > 95%), severe air stagnation, and light attenuation (Alvarez & Torres, 2024; Koberg, 2026). Under prolonged excessive humidity and restricted light penetration, plants exhibit abnormal morphogenetic responses (Kasper et al., 2023). Active indole-3-acetic acid (auxin) accumulates in apical meristems, accelerating internodal cell elongation—a phenomenon classically known as etiolation (Succulentes, 2026; Wulandari et al., 2024).

Conversely, zero air movement paired with vapor-saturated micro-atmospheres severely impairs long-term plant metabolic efficiency (Patel et al., 2023). When atmospheric humidity approaches 100%, the atmospheric vapor pressure deficit drops to near-zero levels, effectively halting passive transpiration (Putra et al., 2021). The cessation of transpirational pull halts the acropetal translocation of essential mobile and immobile nutrients (such as Mg^{2+} and Fe^{2+}) from roots to upper canopy tissues (Irawan et al., 2024; Tanaka & Nakamura, 2023). This nutrient starvation compromises chlorophyll biosynthesis, manifesting visually as foliar chlorosis, stem mechanical flaccidity, and structural collapse (Zulkarnain & Fitriani, 2021). In contrast, open terrarium systems maintain continuous interaction with external atmospheric currents, supplying free CO_2 for Calvin cycle flux while maintaining balanced evapotranspiration rates, albeit requiring strict substrate water management (Pratiwi & Handoko, 2023; Smith & Jones, 2025).

Despite growing scientific literature on microclimate control and closed-system biospheres, existing studies remain overwhelmingly focused on ornamental tropical flora, bryophytes, or succulent species possessing inherently slow metabolic rates and specialized stress adaptations (Djeppu & Ariawan, 2023;

Koberg, 2026). Quantitative comparative evaluations examining the physiological and vegetative growth performance of fast-growing horticultural crops specifically contrasting dicotyledonous fruiting crops like red chili (*Capsicum annuum*) against fast-growing leafy crops like land spinach (*Ipomoea aquatica*) directly from the germination phase remain severely underrepresented in current agricultural literature. Furthermore, most microclimate modification research has focused on open-field or large-scale greenhouse conditions, leaving a critical knowledge gap regarding how extreme moisture saturation in micro-scale artificial containers triggers species-specific morphological trade-offs (etiolation vs. chlorosis).

To address this research gap, this study provides a novel comparative evaluation of microclimate manipulation (open vs. closed terrarium models) on the vegetative growth dynamics, Relative Growth Rate (RGR), and physiological stress symptoms of *Ipomoea aquatica* and *Capsicum annuum*. The novelty of this research lies in revealing species-specific physiological tolerance thresholds under saturated atmospheric moisture stress within isolated micro-ecosystems. The findings of this study offer valuable theoretical insights into plant physiological plasticity under spatial confinement and practical parameters for optimizing micro-scale controlled-environment agriculture (CEA) systems.

Research Methods

This study employed a true experimental design with quantitative and qualitative comparative approaches. It evaluated the effects of microclimate manipulation in two artificial ecosystem models, namely open and closed terrariums, on environmental parameters and the vegetative growth rates of land spinach (*Ipomoea aquatica*) and red chili (*Capsicum annuum*) grown directly from seeds. The experiment was conducted over three weeks, from May 29 to June 12, 2026, at Universitas HKBP Nommensen Pematangsiantar, North Sumatra, Indonesia.

The experimental procedures and the construction of the terrarium systems were executed through a series of systematic workflows. The initial stage began with the preparation of the containers and growing media, which involved securing two clean glass jars as terrarium containers that possessed identical shapes, sizes, and material types. Next, the basal substrate layers were arranged uniformly in both containers, beginning with inserting decorative stones at the absolute bottom as a drainage zone, followed by a layer of charcoal to protect the media quality from fungal growth, and placing a mesh screen separator on top to prevent the soil from leaching downward. Above the mesh screen, the growing medium consisting of humus soil mixed with cow manure was added with equal volume and height in both jars. Once the medium structure was ready, the observation objects were planted; specifically, two seeds of land spinach (*Ipomoea aquatica*) and two seeds of

red chili (*Capsicum annuum*) were planted simultaneously with an identical configuration in both jars. The next step involved adding decorative coral pieces as aesthetic elements on the soil surface of both containers. As the final step of the system assembly, both growing media were evenly watered with an adequate amount of water. The open terrarium model was then left uncovered throughout the study and placed in an area with sufficient sunlight exposure, whereas the closed terrarium model was immediately sealed airtight to trap the humidity inside.

Monitoring and data collection were carried out periodically once a week on May 29 (Week 1), June 5 (Week 2), and June 12 (Week 3). Quantitative data regarding plant stem height were measured using a standard metric ruler (cm), while qualitative data were gathered by observing the final physical conditions of the vegetation, such as leaf color changes (chlorosis symptoms), stem structural firmness, and etiolation symptoms caused by atmospheric humidity. To analyze the relative growth rate (RGR) of plant height from the initial to the final week, the collected quantitative stem growth data were tabulated into an observation matrix table and calculated using the following standard vegetative growth equation (Sitompul, 2022):

$$LPR = \frac{H_t - H_0}{t}$$

Where:

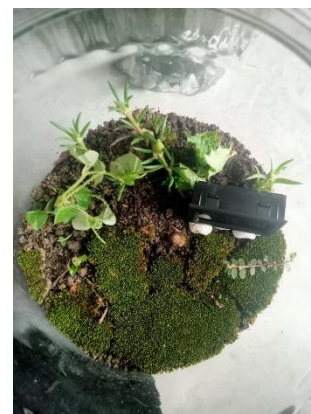
- RGR = Relative Growth Rate (cm/week)
- H_t = Plant height at the final observation week (cm)
- H_0 = Plant height at the initial observation week (cm)
- t = Observation time interval (weeks)

Results and discussion

The initial physical conditions, vegetation types, and substrate arrangements of both artificial ecosystem models prior to experiencing long-term microclimatic fluctuations can be observed in Figure 1 and Figure 2.



Insert Figure 1: Closed Terrarium here



Insert Figure 2: Open Terrarium here

In general, there were highly contrasting microclimatic characteristics between the two artificial ecosystem models. The closed terrarium model created a microenvironment that tended to be extremely wet and humid, whereas the open terrarium model produced a much drier and more stable microenvironment. This divergence occurred purely as a direct consequence of the presence or absence of air mass exchange barriers with the external atmosphere. The humid condition inside the sealed jar was driven by an Isolated Micro-Hydrological Cycle. When the glass lid was sealed airtight, all water from the initial watering, soil evaporation, plant respiration, and foliar transpiration was completely trapped without any outlet. This water vapor accumulated within the highly confined space of the jar. Over time, the internal atmosphere became saturated with moisture, condensed onto the inner glass walls, and precipitated back down to re-moisten the underlying growing medium. This continuous, closed-loop cycle without any air circulation induced an excessively wet and humid internal atmosphere.

Conversely, the drier conditions in the open terrarium were driven by a Free Evapotranspiration Mechanism. Since the jar mouth was left uncovered, the water vapor generated from soil evaporation and plant transpiration did not accumulate inside the container. Instead, the moisture moved freely outward, dispersed by ambient air currents, and blended immediately with the surrounding atmospheric air. This unobstructed free air movement prevented water vapor accumulation or saturation around the plant canopy. Consequently, the micro-atmospheric condition inside the open jar remained significantly drier, and its humidity levels consistently tracked the normal fluctuations of the ambient outdoor air.

The comprehensive data capturing vegetative growth trends alongside the average microclimate inputs across the three-week experimental timeframe are systematically presented in Table 1.

Table 1. Observation Data of Plant Growth Height and Average Microclimate Parameters

Terrarium Type & Plant	Sample	Week 1 (May 29)	Week 2 (June 5)	Week 3 (June 12)	Average Microclimate Parameter (W1 –W3)	Final Physical Condition (June 12)
Open Terrarium Land Spinach (Outdoor)	Plant 1	11.0 cm	16.0 cm	22.0 cm	Temperature: 23.5°C – 27.0°C	Stems are sturdy and erect; leaf coloration is fresh dark green.
	Plant 2	8.0 cm	14.0 cm	20.0 cm	Humidity: 65%	
Closed Terrarium Land Spinach (Indoor)	Plant 1	21.5 cm	32.0 cm	35.0 cm	Temperature: 24.0°C – 25.5°C	Plant 1: Extreme vertical elongation (etiolation); stem bent due to hitting the jar lid. Plant 2: Remained alive; growth was highly stunted due to intense space/light competition.
	Plant 2	7.0 cm	8.5 cm	9.0 cm	Humidity: 96% – 99%	
Open Terrarium Red Chili (Outdoor)	Plant 1	2.5 cm	4.5 cm	7.0 cm	Temperature: 23.5°C – 27.0°C	Stable growth; leaves are fresh green; stems are firm with thin woody structures.
	Plant 2	2.0 cm	4.0 cm	6.5 cm	Humidity: 65%	
Closed Terrarium Red Chili (Indoor)	Plant 1	4.5 cm	6.0 cm	6.5 cm	Temperature: 24.0°C – 25.5°C	Experienced initial etiolation; growth slowed down drastically by Week 3; leaves turned pale yellow (chlorosis); stems became weak due to high humidity without circulation.
	Plant 2	4.0 cm	5.5 cm	5.8 cm	Humidity: 96% – 99%	

Based on the experimental data presented in Table 1, a robust correlation exists between the fluctuations of microclimatic parameters (temperature and air humidity) and the vegetative growth rate as well as the morphological adaptations of both test plants. Within the open terrarium model, the environment remained highly dynamic with stable air humidity at approximately 65% and daily temperature fluctuations ranging between 23.5°C and 27.0°C. This relatively dry microenvironment with unobstructed air circulation proved highly ideal for the growth of red chili (*Capsicum annuum*), where the samples demonstrated a constant increment in height (Plant 1 reached 7.0 cm and Plant 2 reached 6.5 cm) accompanied by the development of firm, slightly woody stem structures and fresh green leaf blades. This stable and proportional growth phenomenon in the open system was also observed in the land spinach (*Ipomoea aquatica*) counterparts, where

Plant 1 advanced to 22.0 cm and Plant 2 reached 20.0 cm, exhibiting erect and robust vegetative structures.

Conversely, the spatial manipulation through container isolation in the closed terrarium model triggered an enclosed micro-hydrological cycle, resulting in a persistent and extreme accumulation of relative air humidity ranging between 96% and 99% with a stagnant temperature profile (24.0°C – 25.5°C). This highly saturated and stagnant atmospheric condition was aggressively responded to by the land spinach through an uncontrolled cell elongation mechanism. Consequently, indoor land spinach Plant 1 exhibited severe etiolation symptoms, shooting up to a height of 35.0 cm within just three weeks, which forced its structure to bend abnormally due to physical space limitations upon striking the upper ceiling of the jar. However, this rapid vertical growth surge provoked intense intraspecific competition for space and light within the container, causing land spinach Plant 2 to undergo severe growth stunting, remaining stagnant at 9.0 cm.

The adverse physiological impacts of a saturated, circulation-free micro-atmosphere in the closed terrarium were most destructively evident in the red chili plants. Although the closed chili samples were initially stimulated by the early moisture during Week 1 growing taller (4.5 cm and 4.0 cm) than those in the open model their growth rate flattened out drastically by Week 3, reaching a final height of only 6.5 cm and 5.8 cm. This extreme moisture stress severely disrupted the natural transpiration process of the chili plants, ultimately triggering severe morphological degradation characterized by weak, flaccid stem structures and chlorosis (the yellowing and paling of leaf blades due to chlorophyll degeneration). Overall, this data analysis confirms that an open terrarium environment with lower humidity and free air circulation is far more supportive for the optimal development of horticultural crops like red chili, whereas a wet, enclosed terrarium environment triggers aggressive stem elongation in land spinach but compromises long-term foliar and structural health.

To precisely evaluate the weekly velocity of these morphological shifts, the quantitative height data were processed to determine the Relative Growth Rate (RGR) of each sample, as displayed in Table 2.

Table 2. Relative Growth Rate (RGR) of Land Spinach and Red Chili Plants

Experimental Model	Plant Type	Sample Code	Initial Height H0 (cm)	Final Height Ht (cm)	RGR (cm/week)	Result
Open Terrarium	Land Spinach (Outdoor)	Plant 1	11.0	22.0	5.50	
		Plant 2	8.0	20.0	6.00	
	Red Chili (Outdoor)	Plant 1	2.5	7.0	2.25	
		Plant 2	2.0	6.5	2.25	
Closed Terrarium	Land Spinach (Indoor)	Plant 1	21.5	35.0	6.75	
		Plant 2	7.0	9.0	1.00	
	Red Chili (Indoor)	Plant 1	4.5	6.5	1.00	
		Plant 2	4.0	5.8	0.90	

Based on the data in Table 2, the calculated Relative Growth Rate (RGR) values clearly map out the contrasting height dynamics between the two artificial ecosystems. The highest RGR value was achieved by the closed land spinach Plant 1 at 6.75 cm/week, confirming an abnormal cell elongation acceleration due to the etiolation phenomenon within the airtight container. Conversely, a drastic decline in growth velocity was observed in the closed red chili Plant 2, which yielded the lowest RGR value at 0.90 cm/week. This baseline metric proves that extreme humidity accumulations reaching up to 99% in the absence of air circulation significantly arrest transpirational flow, thereby reducing the plant's overall metabolic efficiency.



Insert Figure 3: Research Location Map here

Figure 3 illustrates the geographical location of the experimental setup, situated on Jl. Lapangan Sepak Bola, Parhorasan Nauli, Siantar Marihat District, Pematangsiantar City, North Sumatra. The selection of this specific research site served a dual purpose: it provided the natural ambient environmental indicators to control the microclimatic fluctuations affecting the open terrarium system, while

simultaneously serving as the primary monitoring station for tracking the vegetative growth variables of both terrarium models under the local solar radiation profile.

1.1 Microclimatic Dynamics and the Isolated Hydrological Cycle

The highly contrasting environmental parameters recorded between the open and closed terrariums directly stem from the physical boundaries governing air mass and thermal exchange. In the closed terrarium, the airtight sealing completely seals the system, converting it into a thermodynamic trap. Solar radiation penetrates the transparent walls, heating the internal air, soil, and vegetation. This thermal energy accelerates soil evaporation and plant transpiration. However, because the evaporated moisture has no outlet, the micro-atmosphere rapidly reaches its maximum water vapor holding capacity, driving the relative humidity (RH) to an extreme saturation state of 96% - 99%. This high vapor density hits the cooler surface of the jar walls, undergoes continuous condensation, and precipitates back into the soil as artificial rainfall. This isolated cycle locks the system into a permanent high-moisture state with a stagnant temperature profile (24.0°C - 25.5°C). Conversely, the open terrarium functions as an open thermodynamic system. Free convection allows immediate diffusion of water vapor into the surrounding atmosphere, driven by natural wind currents. This prevents vapor accumulation, maintaining a stable, ambient humidity of 65% and allowing normal diurnal temperature fluctuations (23.5°C - 27.0°C).

1.2 Physiological Responses and Growth Rates of Land Spinach (*Ipomoea aquatica*)

The dramatic surge in the Relative Growth Rate (RGR) of the indoor land spinach Plant 1 (6.75 cm/week) provides clear evidence of an aggressive etiolation response triggered by atmospheric stress. In botanical physiology, an environment saturated with moisture combined with reduced light transmittance through container walls blocks the photolytic degradation of auxin (indole-3-acetic acid). The accumulation of active auxin within the apical meristem drives rapid, uncontrolled cell elongation (*elongatio cellulae*) in the stem internodes. This morphogenetic shift is an evolutionary survival mechanism where the plant expends its metabolic energy exclusively on vertical extension to break through the perceived canopy obstruction in search of air circulation and light. However, this rapid vertical expansion by Plant 1 triggered intense intraspecific competition within the highly confined micro-biosphere. Plant 1 rapidly monopolized the limited spatial volume and intercepted the available light path, leaving land spinach Plant 2 under severe light deprivation and physical crowding. Consequently, Plant 2 suffered from acute growth stagnation, yielding a low RGR of only 1.00 cm/week, showcasing how micro-spatial limits shift uniform crop development into extreme size asymmetry.

1.3 Destructive Effects of Extreme Humidity on Red Chili (*Capsicum annuum*)

While the high-humidity closed system induced rapid elongation in land spinach, it exerted a highly destructive physiological toll on the red chili plants, evidenced by a drop in RGR to a minimal 0.90 cm/week. Red chili (*Capsicum annuum*) is highly sensitive to water logging and atmospheric saturation. When the external relative humidity climbs to 99%, the vapor pressure deficit (VPD) between the internal substomatal cavities of the leaves and the surrounding micro-atmosphere drops to zero. This absolute equilibrium completely halts the plant's transpirational pull. The cessation of transpiration terminates the passive acropetal transport of water and dissolved mineral ions through the xylem from the roots to the shoots. As a result, the chili plants suffered from severe nutrient starvation, specifically lacking magnesium (Mg^{2+}) and nitrogen ions, which are crucial structural central blocks for chlorophyll biosynthesis. The breakdown of chlorophyll molecules manifested visually as severe foliar chlorosis (yellowing). Furthermore, the absence of active water movement reduced cellular turgor pressure within the parenchymal tissues, causing the mechanical collapse of the stem structure, rendering it completely flaccid and weak.

Conclusion

Spatial characteristics and air circulation barriers significantly dictate microclimatic regimes, driving species-specific physiological and morphological responses in horticultural crops. The open terrarium maintains stable environmental conditions (RH 65%; 23.5°C–27.0°C), supporting proportional vegetative growth, sturdy stem structures, and optimal leaf health for both *Ipomoea aquatica* and *Capsicum annuum*. Conversely, spatial isolation in the closed terrarium forms an enclosed micro-hydrological cycle with extreme atmospheric humidity saturation (RH 96%–99%) and stagnant temperatures (24.0°C–25.5°C). This moisture-saturated environment induces rapid etiolation in *Ipomoea aquatica*, accelerating abnormal stem elongation up to 35.0 cm (RGR: 6.75 cm/week), whereas it severely degrades *Capsicum annuum* growth by inhibiting transpiration, leading to growth stagnation (RGR: 0.90 cm/week), weak stems, and foliar chlorosis. In conclusion, open terrariums are essential for the healthy cultivation of sensitive fruiting crops like red chili, while closed terrariums trigger hyper-elongation in land spinach at the expense of long-term structural quality.

Suggestion

Based on the research findings, it is highly recommended that stakeholders and future researchers pursuing indoor agricultural cultivation or micro-biosphere modeling avoid fully airtight, enclosed systems for horticultural crops, particularly for sensitive species like red chili. Future studies should integrate automated micro-

ventilation mechanisms or manual aeration schedules to prevent moisture saturation. Additionally, expanding the monitoring parameters to include stomatal conductance tracking, chlorophyll density measurements, and varied soil substrate layouts would highly improve the accuracy and practical utility of subsequent microclimatic research.

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