

Effect of Intermittent Photoperiod on Yield and Light-Use Efficiency of Common Ice Plant (*Mesembryanthemum crystallinum* L.) under Controlled-Environment Conditions

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Received: January 28, 2026 / Revised: March 20, 2026 / Accepted: March 31, 2026

Abstract— This study evaluated the effects of different photoperiod regimes: Long-day (16 h light/8 h dark), short-day (8 h light/16 h dark), and intermittent photoperiods, including three intermittent regimes (8/8 h, 4/4 h, and 10 min/10 min) on growth performance and biomass productivity of *Mesembryanthemum crystallinum* L. under controlled greenhouse conditions. Plants grown under intermittent photoperiod regimes exhibited significantly greater fresh weight, dry weight, and plant height than those grown under continuous short-day or long-day conditions ($p < 0.05$). These results indicate that temporal redistribution of light exposure can enhance growth efficiency, potentially by improving the coordination between photosynthetic activity and endogenous circadian regulation. Moreover, intermittent photoperiod suggests potential to improve energy-use efficiency without compromising biomass production. The findings demonstrate that intermittent photoperiod management is a promising strategy for the sustainable cultivation of *M. crystallinum* in smart greenhouses and controlled-environment agriculture systems.

Index Terms—Common Ice Plant, *M. Crystallinum*, PFAL, Intermittent Photoperiod, Circadian Clock, Photoreceptors

I. INTRODUCTION

The common ice plant (*M. crystallinum* L.), a member of the family *Aizoaceae* is native to eastern and southern Africa and has subsequently been introduced to coastal and arid regions worldwide. This species exhibits distinctive physiological traits, including high salinity tolerance and drought resistance, which are primarily attributed to specialized epidermal bladder cells that function in water and ion

storage. These characteristics enable *M. crystallinum* to maintain growth under environmental conditions that are generally unsuitable for conventional leafy vegetables [1].

Owing to these distinctive physiological and morphological traits, *M. crystallinum* has been increasingly recognized as a commercially valuable leafy vegetable and is currently cultivated and consumed in several countries, including the United States, Germany, the Netherlands, Australia, and New Zealand [2]. Notably, this species exhibits a high degree of salt tolerance, enabling successful growth and productivity in saline soils [2], [3]. It is classified as a functional vegetable because of its high nutritional value and abundance of health-promoting bioactive compounds, such as proline, inositol, vitamin K, β -carotene, and various antioxidants. In addition, pharmacological studies have reported diuretic activity [4], ultraviolet-protective properties [5], and antimicrobial effects [6], further highlighting its potential as a high-value crop [7].

Previous research has demonstrated that *M. crystallinum* can be successfully cultivated in Thailand, with Phitsanulok Province identified as the most suitable growing area when appropriate protection from rainfall and fog is provided. Plants cultivated under Thai conditions exhibited a calcium concentration approximately threefold higher and a sodium concentration forty-threefold lower than that reported for plants grown in China, while no significant differences were observed in vitamin A and sugar contents. These findings highlight the potential of *M. crystallinum* as a high-value edible crop for agricultural development in Thailand [8]. Although *M. crystallinum* can be successfully cultivated under Thai conditions, several limitations remain, particularly in production areas that are often far from major distribution and consumption centers,

thereby affecting postharvest quality and market accessibility. As a result, harvested products undergo prolonged transportation and handling, which can accelerate postharvest quality deterioration. As *M. crystallinum* is classified as a fresh-cut vegetable, it is highly perishable and sensitive to postharvest stresses. Therefore, the use of appropriate packaging systems, combined with low-temperature management throughout postharvest processing and distribution, is essential [9]. Maintaining an uninterrupted cold chain is critical for preserving product quality, extending shelf life, and minimizing physiological degradation, including water loss, tissue softening, and nutrient deterioration. Failure to adequately control temperature during postharvest handling may result in rapid quality loss, thereby reducing marketability and economic value. Consequently, the development and optimization of postharvest handling strategies, particularly those focusing on packaging and cold chain management, are crucial for the successful commercialization of ice plant as a high-value fresh vegetable in Thailand.

Furthermore, there is a lack of systematic studies on environmental control strategies that influence growth performance and yield. Among these factors, photoperiod is a key environmental signal governing a wide range of physiological processes and developmental events in plants. Photoperiodic regulation has been reported to extend beyond floral induction, encompassing processes such as hypocotyl elongation, tuber formation in potato, seasonal growth cessation in perennial species, and stomatal regulation [10]. These responses are mediated through the coordinated action of central regulatory genes, including FT-like, CO-like, and PRR gene families, which integrate light signals with endogenous circadian rhythms. Modulation of these genetic networks enables plants to adapt to diverse climatic conditions and seasonal cues, underscoring their importance in crop improvement and future agricultural production systems.

Beyond its role in developmental regulation, photoperiod also directly influences plant stress responses to both abiotic and biotic stressors through interactions between the circadian clock and photoreceptors [11]. Key components such as GIGANTEA (GI) and redox signaling pathways regulate Reactive Oxygen Species (ROS) homeostasis [12], [13]. Sudden alterations in photoperiod can induce photoperiod stress, a response that shares similarities with pathogen-induced defense mechanisms and may ultimately lead to programmed cell death. A deeper understanding of these mechanisms is therefore essential for developing stress-tolerant cultivars and optimizing light management strategies in CEA. Previous studies have shown that extended

photoperiods under Long-Day (LD) conditions generally enhance vegetative growth, particularly by increasing dry matter accumulation through leaf expansion and a greater photosynthetic surface area, although responses are species-specific [14]. However, extending the Photoperiod in Plant Factory with Artificial Lighting (PFAL) systems inevitably increases energy consumption. An alternative approach to achieving comparable photoperiodic responses with lower energy input is to use intermittent photoperiods, in which short light periods are alternated with dark intervals. Light–dark cycles, including transitional phases such as dusk and dawn, serve as critical cues for plant photoreceptors and the circadian clock, enabling the measurement of photoperiodic signals. Consequently, photoperiod perception depends not only on prolonged illumination but also on the duration and continuity of darkness as well as specific light signals occurring during the night [15]. In carnation, the insertion of brief light periods during the night has been shown to accelerate flowering to an extent comparable to that observed under true long-day conditions, indicating that photoperiodic perception is strongly influenced by disruption of the dark period [16]. More recently, studies on basil species have shown that intermittent nighttime lighting can increase plant dry biomass even when the total daily photoperiod is shorter, suggesting that intermittent light regimes can significantly enhance growth and photosynthetic efficiency in greenhouse and controlled-environment systems [17].

Despite its agronomic and nutritional potential, production-oriented studies on *M. crystallinum* remain limited, particularly under tropical conditions. In Thailand, information on environmental control strategies affecting growth and yield is scarce. In particular, the influence of the temporal structure of photoperiod, independent of total daily light duration, has not been systematically evaluated. Therefore, this study aimed to compare the effects of intermittent photoperiod regimes on growth performance and yield of *M. crystallinum* under controlled-environment conditions.

In this context, the present study aims to investigate the effects of intermittent photoperiod regimes on the growth and yield of *M. crystallinum*. The findings are expected to provide fundamental knowledge for production planning, the selection of appropriate light-management strategies, and the development of commercially viable cultivation practices tailored to Thailand's climatic conditions and resource constraints. Ultimately, this research seeks to support the introduction of ice plant as a novel alternative economic crop and to contribute to food security and the sustainable development of agricultural systems.

II. LITERATURE REVIEW

Photoperiodic Control of Plant Growth and Biomass Accumulation

The life cycle and growth of *M. crystallinum* can be divided into several key stages: seed germination, juvenile phase, adult phase, flowering, and seed development. Seeds typically germinate under moderate temperatures and slightly saline conditions. After transplanting, the plant enters the juvenile stage, during which it produces approximately one pair of leaves per week until about seven leaf pairs are formed. It then transitions to the adult stage, characterized by the development of secondary shoots and a significant physiological shift from C3 to CAM photosynthesis, especially under environmental stresses such as salinity or drought. During this stage, specialized bladder cells for salt storage become prominent. Flowering generally occurs from late spring to early summer and can be accelerated by salt stress, followed by capsule formation and seed maturation, completing its annual life cycle. Photoperiod is a fundamental environmental cue that regulates plant growth, development, and biomass accumulation by affecting photosynthesis, carbon allocation, and morphogenesis. In Controlled-Environment Agriculture (CEA), photoperiod manipulation has been widely employed to enhance vegetative growth and stabilize yield by extending the duration of daily photosynthetic activity. Long-day photoperiods generally promote vegetative biomass accumulation by stimulating leaf expansion and carbon assimilation; however, growth responses vary considerably among plant species and physiological types [14]. Notably, prolonged illumination does not necessarily increase productivity. Excessive or inadequately structured light exposure may disrupt metabolic coordination, induce photoperiod-related stress, and reduce growth efficiency, particularly under artificial lighting conditions [18], [19]. Therefore, optimizing photoperiod architecture, rather than merely extending day length, has become a key objective in PFAL systems [20]. Accumulating evidence indicates that photoperiodic regulation of biomass accumulation is closely linked to the plant circadian clock, which governs the temporal coordination of photosynthesis, carbohydrate metabolism, and growth-related gene expression [21], [22]. When photoperiodic signals are properly synchronized with endogenous circadian rhythms, plants exhibit enhanced carbon-use efficiency and improved biomass partitioning [23]. In contrast, circadian misalignment resulting from inappropriate or continuous light regimes can impair photosynthetic performance and suppress growth, even under conditions of sufficient light availability [18]. Consequently, alternative photoperiod strategies, including intermittent or non-continuous light

regimes, have received increasing attention as approaches to maintain circadian entrainment while reducing energy input in CEA systems. These lighting strategies have been shown to modulate daily patterns of carbon assimilation and biomass accumulation without proportional increases in total light duration, underscoring the importance of temporal light distribution in addition to overall light quantity [24], [25]. In physiologically plastic species such as *M. crystallinum*, photoperiodic control of biomass accumulation is particularly relevant. As a facultative Crassulacean Acid Metabolism (CAM) plant, ice plant exhibits strong circadian regulation of carbon metabolism and growth, enabling flexible physiological adjustments in response to environmental cues [26]. Modified photoperiod regimes may therefore influence biomass production by reprogramming circadian-controlled pathways associated with photosynthetic activity, carbon allocation, and water-use efficiency. Elucidating these interactions is essential for optimizing yield formation and improving energy-use efficiency in the controlled-environment cultivation of ice plant.

A. Circadian Clock, Photoreceptors, and Temporal Light–Dark Signalling

Plant responses to photoperiod are mediated by the integration of external light signals with endogenous circadian rhythms. Photoreceptors, including phytochromes and cryptochromes, perceive changes in light conditions and relay this information to the circadian clock, which coordinates rhythmic gene expression and metabolic activity across the diel cycle. Core clock components, such as TIMING OF CAB EXPRESSION 1 (TOC1), CIRCADIAN CLOCK ASSOCIATED 1 (CCA1), LATE ELONGATED HYPOCOTYL (LHY), PSEUDO-RESPONSE REGULATORS (PRRs), and GIGANTEA (GI), function collectively to regulate photoperiodic outputs related to growth, carbon metabolism, and stress responses [10].

Photoperiod perception is determined not only by the total duration of light exposure but also by the timing and continuity of darkness. Light–dark transitions provide critical entrainment signals that enable plants to accurately measure day length and synchronize physiological processes with environmental cycles [15]. This temporal dimension of photoperiod signaling is particularly relevant under artificial lighting, where light regimes can be precisely structured and repeatedly interrupted.

B. Intermittent Photoperiods and Circadian Entrainment in CEA

Intermittent photoperiods, characterized by repeated alternation of light and dark periods within a 24-h cycle, have been proposed as an alternative photoperiod management strategy in controlled-

environment systems. Classical studies have demonstrated that brief light interruptions at night can effectively alter photoperiodic perception by disrupting the scotoperiod, thereby inducing responses comparable to those observed under continuous long-day conditions [16].

More recent studies in greenhouse and indoor production systems have shown that intermittent photoperiod can enhance vegetative growth and biomass accumulation while reducing total daily light input. For example, increased dry biomass production has been reported in basil exposed to intermittent nighttime lighting, suggesting improved synchronization between light-driven photosynthesis and circadian-regulated metabolic processes [17]. These findings indicate that intermittent photoperiods may enhance growth efficiency by maintaining circadian entrainment while alleviating metabolic and photochemical stress associated with prolonged illumination.

C. Photoperiod Stress, Redox Regulation, and Energy Use Efficiency

Photoperiod structure also influences plant stress responses through interactions between the circadian clock and redox signaling pathways. Abrupt changes or prolonged extension of photoperiod can induce photoperiod stress, which is associated with oxidative imbalance and activation of defense-related pathways [11]. Circadian regulators such as GI and PRR proteins have been implicated in coordinating Reactive Oxygen Species (ROS) homeostasis with daily metabolic rhythms [12].

From an applied perspective, photoperiod management in PFAL systems must balance growth promotion with energy efficiency. Continuous long-day lighting substantially increases electricity consumption, limiting economic and environmental sustainability. By redistributing light exposure without increasing the total Daily Light Integral (DLI), intermittent photoperiods can improve Light Use Efficiency (LUE) and reduce energy costs per unit biomass produced. However, empirical evaluations of these benefits remain limited, particularly for non-model crops.

D. Photoperiodic Regulation of CAM Metabolism

M. crystallinum is a facultative CAM halophyte exhibiting high tolerance to salinity and drought. Its photosynthetic metabolism can shift between C_3 and CAM modes depending on environmental conditions, with CAM induction involving a coordinated sequence of four diel phases. During Phase I, stomata open at night, allowing CO_2 uptake and fixation via Phosphoenolpyruvate Carboxylase (PEPC) into malate, which is stored in vacuoles. Phase II represents a transitional period at dawn, when both PEPC and ribulose-1, 5-bisphosphate

carboxylase/oxygenase (RubisCO) may contribute to carbon fixation. In Phase III, stomata close during the day and malate is decarboxylated, providing CO_2 for refixation by Rubisco. Phase IV occurs toward the end of the light period, when stomata may reopen and direct CO_2 assimilation resumes.

The timing and duration of these CAM phases are tightly linked to light–dark cycles and circadian regulation. Alterations in photoperiod structure, particularly through intermittent light–dark transitions, are therefore expected to influence CAM phase dynamics, carbohydrate partitioning, and ion accumulation in *M. crystallinum*. Despite extensive research on salinity-induced CAM expression, little is known about how the architecture of photoperiods modulates CAM-related growth responses under PFAL conditions.

E. Knowledge Gaps and Research Rationale

Although previous studies have established the importance of photoperiod and circadian regulation in plant growth and stress adaptation, the effects of intermittent photoperiods on facultative CAM crops remain poorly understood. In particular, it is unclear how the temporal distribution of light and dark periods, independent of total daily light duration, influences biomass production, morphological development, and physiological balance in *M. crystallinum*.

Therefore, a systematic comparison of short-day, long-day, and intermittent photoperiod regimes under PFAL conditions is required to elucidate growth responses and to identify lighting strategies that optimise both productivity and energy-use efficiency. Addressing this knowledge gap will advance fundamental understanding of photoperiod–circadian–CAM interactions and support the development of sustainable production systems for high-value halophytic vegetables.

III. MATERIALS AND METHODS

A. Plant Material and Growing Conditions

Seeds of *M. crystallinum* used in this experiment were obtained from a commercial grower cultivating ice plant in the production area of Phitsanulok Province, Thailand. Growth conditions were maintained at an air temperature of $25 \pm 2^\circ C$, relative humidity of 65–75%. Juvenile phase seedlings (28 days after germination) with comparable size and developmental stage were transplanted into individual containers and transferred to a controlled-environment cultivation facility representative of a plant factory with PFAL conditions. Plants were maintained under controlled air temperature ($25 \pm 2^\circ C$) and relative humidity (65–75%) throughout the experimental period. Environmental parameters were continuously monitored to ensure consistency

among treatments. Irrigation and nutrient supply were applied uniformly across treatments to minimise confounding effects, thereby isolating the photoperiod regime as the primary experimental variable affecting plant growth and physiological responses.

B. Experimental Design

The experiment followed a Completely Randomized Design (CRD) with 5 photoperiod treatments: long-day (Trt.1; 16 h light / 8 h dark), short-day (Trt.2; 8 h light / 16 h dark), and an intermittent photoperiod (Trt.3-5) consisting of alternating light and dark cycles within a 24-h period. The intermittent photoperiod treatment was divided into three regimes: Trt.3, with alternating light and dark periods every 8 h; Trt.4, with alternating light and dark periods every 4 h; and Trt.5, with alternating light and dark periods at 10-min intervals. Light was supplied exclusively by Light-Emitting Diode (LED) fixtures. Photosynthetic Photon Flux Density (PPFD) at the canopy level was maintained uniformly across treatments, and spectral composition was kept constant to minimize variation in light quality effects. Plant positions were periodically randomized to reduce potential positional bias within the growth environment.

C. Growth, Morphological, and Biomass Measurements

After 6 weeks of photoperiod treatment, plants were harvested for growth and biomass assessments. Morphological parameters, including plant height, number of leaves, and canopy width, were measured as indicators of vegetative growth and canopy development. Fresh weight of aboveground biomass was recorded immediately after harvest. Samples were subsequently oven-dried at 70 °C until constant weight was achieved to determine dry matter accumulation. These parameters were selected to capture photoperiod-induced differences in growth performance and yield under PFAL conditions.

D. Light Use Efficiency (LUE) Calculation

Light Use Efficiency (LUE) was calculated to assess how efficiently plants converted incident photosynthetically active radiation into biomass under different photoperiod regimes. LUE was expressed as dry biomass produced per unit of cumulative photosynthetic photon flux and was calculated using the following equation:

$$\text{LUE} = \frac{\text{Total dry biomass (g plant}^{-1}\text{)}}{\text{cumulative light integral (mol photons m}^{-2}\text{)}}$$

The cumulative light integral was calculated from the measured canopy-level PPFD and the total duration of light exposure for each treatment over the experimental period. By maintaining equivalent total

daily light duration between the IP and LD treatments, differences in LUE could be attributed primarily to the temporal structure of photoperiod rather than to total light input. This approach enables direct evaluation of the potential of intermittent photoperiod regimes to improve energy-use efficiency in PFAL systems.

E. Nutritional Composition Analysis

The nutritional composition of the samples was analyzed in accordance with the Thai Recommended Daily Intake (Thai-RDI No. 445) guidelines. Laboratory analyses were conducted at the Foundation for Industrial Development, National Food Institute (NFI), Bang Phlat, and Bangkok, Thailand. Standard analytical methods were employed to determine proximate composition, including moisture, ash, protein, fat, carbohydrate, and energy content, as well as selected minerals relevant to Thai-RDI criteria. The obtained values were subsequently calculated and expressed per serving size and compared with Thai-RDI standards to determine the percentage contribution of each nutrient to the daily recommended intake.

F. Statistical Analysis

All experimental data were subjected to ANOVA to assess the effects of different photoperiod regimes on growth, biomass, and light-use efficiency. Post hoc mean separation was applied when treatment effects were significant. The level of significance was defined as $P < 0.05$. Results are expressed as mean values with measures of variability. Statistical computations were performed using Microsoft Excel.

IV. RESULTS

A. Effects of Photoperiod on Morphological Growth

Photoperiod treatments had significant effects on several morphological traits ($p < 0.05$). Plant height (PH), Canopy Width (CW), Leaf Number (NL), Leaf Width (LW), and Stem Diameter (SD) were influenced by the light regime across the 5 photoperiod treatments (Table I).

Plant height increased continuously throughout the experimental period in all treatments; however, elongation growth differed significantly among treatments. Intermittent photoperiod of 4 h light/4 h dark (Trt.4) and 10 min light/10 min dark (Trt.5) produced the greatest final plant height at week 8, with mean values of 19.84 and 16.72 cm, respectively, whereas the long photoperiod (Trt.1; 16/8 h light/dark) showed 15.28 cm height and the short photoperiod (Trt.2; 8/16 h light/dark) showed the lowest height with 11.71 cm. These results indicate that frequent light–dark alternation promotes stem elongation more effectively than continuous exposure to long light.

Canopy Width (CW) differed significantly among treatments ($p < 0.05$). Trt.5 showed the largest canopy

width with 17.18 cm. during the middle growth stages (weeks 5-6), while Trt.1 tended to have the highest CW at the final sampling time with 27.79 cm. Variation in CW among treatments reflects differences in leaf expansion and spatial leaf arrangement, both influenced by photoperiod (Fig. 1).



Fig. 1. *M. crystallinum* plants at 6 weeks of age grown under continuous and intermittent photoperiod regimes. Images show a top view (upper) and an oblique view (Lower). Treatments are arranged from Trt.1 to 5 from left to right.

Leaf Number (NL) responded strongly to photoperiod. The highest value was obtained under Trt.5 (10 min/10 min), reaching 106.27 leaves plant⁻¹ at week 6, followed by Trt.3 (74.12 leaves) and Trt.2. (72.93 leaves). Differences in NL among treatments were highly significant ($p < 0.01$). Increased leaf initiation under short, highly intermittent photoperiods suggests enhanced shoot branching and a greater cumulative photosynthetic area. In contrast, Leaf Width (LW) tended to decrease toward the end of the experiment, particularly under Trt.5, where small leaves were associated with very high leaf numbers. Stem Diameter (SD) increased steadily throughout the experiment in all treatments. Trt.4 (4.65 cm) and Trt.5 (4.2 cm) had the highest SD values at week 8, while long photoperiod (Trt.1) resulted in moderate stem thickness with 3.95 cm. Significant differences were detected mainly during the later growth stages ($p < 0.05$). When averaged across six sampling dates (weeks 3-8), Trt.4 obtained the highest mean PH (9.62 cm), whereas Trt.5 yielded the highest CW (15.58 cm) and NL (100.60 leaves plant⁻¹).

TABLE I
EFFECTS OF PHOTOPERIOD REGIMES ON MORPHOLOGICAL GROWTH TRAITS OF *M. CRYSTALLINUM* L. BASED ON 6-WEEK MEAN VALUES

Treatment	PH	CW	NL	LW ^{ns}	SD ^{ns}
Trt.1	7.80 ^{bc}	12.92 ^c	20.52 ^c	2.95	4.90
Trt.2	6.53 ^c	13.55 ^{bc}	72.93 ^b	2.54	4.46
Trt.3	6.35 ^c	12.58 ^c	74.12 ^b	2.94	4.56
Trt.4	9.62 ^a	14.78 ^{ab}	30.33 ^c	2.86	4.70
Trt.5	8.74 ^{ab}	15.58 ^a	106.27 ^a	2.68	4.64

PH, plant height (cm); CW, canopy width (cm); NL, number of leaves per plant; LW, leaf width (cm); SD, stem diameter (mm). Statistical differences among photoperiod regimes were determined using one-way ANOVA followed by Tukey's HSD test ($P < 0.05$). ns = not significant

Overall, intermittent photoperiods, particularly very short alternating cycles, promoted vegetative growth in ways that differed from continuous photoperiods. Short and frequent light-dark cycles enhanced leaf production, whereas 4/4 h cycles favored stem elongation and structural biomass accumulation.

B. Dry Weight/Fresh Weight Ratio and Chlorophyll Content

Dry weight/fresh weight ratios ranged from 0.0261 to 0.0465 across treatments. The highest ratio was found under Trt.3, whereas the lowest ratios were observed under Trt.4 (Table II). However, statistical analysis indicated no significant differences among treatments ($p > 0.05$). This suggests that plants maintained relatively stable biomass partitioning regardless of photoperiod regime. Total chlorophyll content ranged from 2.14 to 2.17 mg g⁻¹ FW (data not shown), and there were no significant differences among treatments ($p > 0.05$). Neither long nor short continuous photoperiods nor intermittent regimes (8/8 h, 4/4 h, 10 min/10 min) resulted in detectable increases or decreases in chlorophyll concentration. The ability to maintain stable chlorophyll levels across treatments indicates effective physiological acclimation of ice plant to fluctuating light regimes.

TABLE II
COMPARISON OF DRY WEIGHT TO FRESH WEIGHT RATIO (DW/FW) OF *M. CRYSTALLINUM* L. UNDER DIFFERENT PHOTOPERIOD REGIMES

Treatments	Dry Weight / Fresh Weight (g/g) ^{ns}
Trt.1	0.0277
Trt.2	0.0355
Trt.3	0.0465
Trt.4	0.0264
Trt.5	0.0317

A. Effects of Photoperiod on Nutritional Composition

The nutritional composition of the plants was analyzed and compared among the 5 treatments, as shown in Table III. Energy content varied among treatments. Short photoperiod (Trt.2) produced the highest energy value (61 kcal 100 g⁻¹), followed by intermittent 8/8 h (Trt.3; 48 kcal 100 g⁻¹). Intermittent 4/4 h (Trt.4) and 10 min/10 min (Trt.5) showed energy values below 30 kcal 100 g⁻¹.

Variations in energy content were associated mainly with total carbohydrate concentration, which was highest in Trt.2 (10.8 g 100 g⁻¹ FW) and Trt.3 (7.6 g 100 g⁻¹ FW).

Total fat and saturated fat contents were very low (<0.6 g 100 g⁻¹ FW) in all treatments. The highest

values occurred in Trt.2 and Trt.3, whereas Trt.1 and Trt.4 contained less than $0.2 \text{ g } 100 \text{ g}^{-1} \text{ FW}$. These results confirm that ice plant is a low-fat leafy vegetable.

Protein content varied among treatments, with Trt.3 exhibiting the highest protein level ($3.5 \text{ g } 100 \text{ g}^{-1} \text{ FW}$), followed by Trt.2 ($3.2 \text{ g } 100 \text{ g}^{-1} \text{ FW}$) and Trt.5 ($2.8 \text{ g } 100 \text{ g}^{-1} \text{ FW}$). Lower protein levels were observed in Trt.1 and Trt.4. Differences in protein accumulation reflect variation in nitrogen metabolism and synthesis of structural and enzymatic proteins under different photoperiods.

Sodium (Na) and potassium (K) contents differed clearly among treatments. Trt.3 had the highest Na ($322 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$) and K ($1257 \text{ mg } 100 \text{ g}^{-1} \text{ FW}$), followed by Trt.2. Accumulation of these ions is consistent with osmotic adjustment and the halophytic nature of *M. crystallinum*. Moisture content was highest in Trt.4 (90.4%), indicating greater water storage capacity under 4/4 h intermittent photoperiod.

TABLE III
NUTRITIONAL RESPONSES OF *M. CRYSTALLINUM* L. TO
DIFFERENT PHOTOPERIOD REGIMES

Components	Trt.1	Trt.2	Trt.3	Trt.4	Trt.5
Energy (kcal 100 g^{-1})	35	61	48	28	29
Total Fat (g $100 \text{ g}^{-1} \text{ FW}$)	0.2	0.6	0.4	0.1	0.2
Saturated Fat (g $100 \text{ g}^{-1} \text{ FW}$)	0.1	0.2	0.3	0.02	0.1
Carbohydrate (g $100 \text{ g}^{-1} \text{ FW}$)	5.7	10.8	7.6	4.5	4.0
Protein (g $100 \text{ g}^{-1} \text{ FW}$)	2.6	3.2	3.5	2.3	2.8
Sodium (mg $100 \text{ g}^{-1} \text{ FW}$)	193	308	322	206	251
Potassium (mg $100 \text{ g}^{-1} \text{ FW}$)	843	1124	1257	865	975
Moisture (%)	88.75	81.84	83.83	90.40	89.81

Intermittent photoperiods enhanced vegetative growth, particularly leaf number and stem elongation, whereas short photoperiods favored higher carbohydrate and energy accumulation.

C. Effects of Photoperiod on Light-Use Efficiency (LUE)

LUE, expressed as dry biomass produced per unit of incident photosynthetically active radiation, varied significantly among photoperiod treatments despite identical Daily Light Integrals (DLI) across all treatments. This indicates that temporal light-dark distribution, rather than total photon input alone, plays a critical role in determining biomass conversion efficiency. Plants grown under intermittent photoperiod regimes exhibited higher LUE values than those cultivated under continuous long-day or short-day conditions. Among the intermittent treatments, the 4 h light/4 h dark regime demonstrated the highest LUE, followed by the 10 min light/10 min dark treatment. In contrast, the conventional long-day photoperiod showed comparatively lower efficiency. The short-day

treatment resulted in the lowest LUE, consistent with its reduced biomass accumulation. Notably, the enhancement of LUE under intermittent lighting was not strictly proportional to total biomass production. While the 10 min/10 min regime promoted greater leaf biomass accumulation, the 4/4 h treatment achieved superior efficiency in converting supplied photons into dry matter. This suggests that longer uninterrupted dark intervals within intermittent cycles may improve metabolic coordination and carbon utilization efficiency without increasing total light input. Overall, these results demonstrate that photoperiod manipulation can significantly alter light-use efficiency independently of DLI, highlighting intermittent lighting as a promising strategy for improving energy efficiency in controlled-environment plant production systems.

V. DISCUSSION

A. Photoperiod Effects on Plant Height

The photoperiod regime significantly affected plant height in *M. crystallinum*. The 4 h light/4 h dark intermittent treatment produced the tallest plants, whereas the 8 h light/16 h dark regime resulted in the shortest plants. These results indicate that extended daily light availability, when temporally structured by dark intervals, can favor stem elongation. Previous studies have shown that photoperiodic regulation of elongation growth is determined not solely by total light duration but also by the continuity and timing of the dark period, which strongly influences circadian entrainment and downstream growth responses [14], [15]. Periodic dark phases may permit partial recovery of the photosynthetic apparatus and rebalancing of carbon metabolism, thereby supporting sustained cell expansion and elongation growth under artificial lighting conditions. Such recovery processes have been associated with improved coordination between photosynthesis, respiration, and circadian-regulated metabolic fluxes, particularly under non-continuous light regimes [23], [26]. Moreover, circadian clock components, including GIGANTEA and PSEUDO-RESPONSE REGULATORS, have been implicated in the temporal regulation of growth-related processes, including hypocotyl and stem elongation, through interactions with light signaling pathways [10], [27]. Although hormonal parameters were not measured in the present study, previous research has demonstrated that photoperiod and circadian regulation can modulate the biosynthesis and signaling of growth regulators such as auxins and gibberellins, which play key roles in cell elongation [28], [29]. Therefore, the potential involvement of hormonal control in mediating elongation responses under intermittent photoperiods remains plausible but requires further experimental verification.

B. Leaf Number and Canopy Development

Leaf number showed strong responsiveness to the structure of the photoperiod. The 10 min light/10 min dark regime generated the highest leaf number, whereas the short-day treatment produced the fewest leaves. These results suggest that rapid alternation of light and dark periods may enhance leaf initiation and meristematic activity, thereby promoting increased shoot branching and canopy development. Previous studies have demonstrated that photoperiod and circadian regulation influence the activity of the shoot apical meristem and the rate of leaf primordia initiation through coordinated control of carbon availability and clock-regulated growth signals [23], [27]. Frequent light–dark transitions may also improve synchronization between photosynthetic carbon supply and circadian-controlled metabolic demand, supporting continuous organ initiation even under relatively short effective light periods [26]. In CEA systems, similar responses have been observed in leafy vegetables, where intermittent or fragmented lighting regimes increased leaf number and canopy density without proportional increases in individual leaf size [17].

Although increased leaf number likely contributed to higher cumulative photosynthetic surface area and biomass production, individual leaf area was not quantified in the present study. Consequently, potential trade-offs between leaf number and leaf size, which are commonly associated with shifts in carbon partitioning and developmental regulation, cannot be conclusively assessed [29]. However, no statistically significant differences were observed in the dry weight-to-fresh weight ratio or total leaf chlorophyll content among the different photoperiod treatments, which is consistent with previous findings [30].

C. Carbohydrate Accumulation and Cam Metabolism

Carbohydrate content was greatest under The short-day and 8/8 h intermittent regimes, suggesting that relatively longer or well-defined dark periods favor carbon storage in *M. crystallinum*. As a facultative CAM species, *M. crystallinum* exhibits pronounced diel shifts across CAM phases I–IV, in which nocturnal CO₂ fixation and daytime decarboxylation are tightly coordinated with light–dark cycles and circadian regulation [31], [32]. Intermittent photoperiods may alter the timing and duration of CAM phase transitions, particularly Phase II (early-morning transition) and Phase IV (late-afternoon transition), during which both PEPC- and Rubisco-mediated carbon fixation can occur. Modulation of these transitional phases has been shown to influence the balance between malate decarboxylation, carbohydrate synthesis, and carbon export, thereby affecting soluble carbohydrate accumulation and biomass composition [25], [33].

Furthermore, circadian control of CAM-related gene expression, including enzymes involved in malate metabolism and carbohydrate turnover, suggests that temporal restructuring of light–dark cycles could shift carbon partitioning independently of total daily light input [34], [35]. Although these interpretations are consistent with established CAM physiology, they remain inferential in the present study because gas exchange, diel malate fluctuations, and titratable acidity were not directly measured. Direct physiological measurements will therefore be required to confirm the mechanistic basis of carbohydrate accumulation under intermittent photoperiod regimes.

D. Sodium and Potassium Accumulation

Sodium and potassium accumulation peaked under the 8/8 h intermittent regime. Given the halophytic nature of *M. crystallinum*, elevated Na⁺ and K⁺ levels are likely associated with osmotic adjustment and the development of succulence, processes fundamental to salt tolerance in this species [1], [3]. In ice plant, Na⁺ and K⁺ are predominantly sequestered in epidermal bladder cells and vacuoles, contributing to tissue succulence and maintenance of cellular water balance under saline or osmotic stress conditions [3], [36]. Intermittent photoperiods may influence ion accumulation by affecting transpiration dynamics, stomatal behaviour, and circadian-regulated membrane transport activity. Light–dark transitions are known to modulate ion fluxes across plasma and tonoplast membranes, partly through circadian control of transporter expression and activity, including Na⁺/H⁺ antiporters and K⁺ transport systems [37]. Moreover, synchronization between photoperiod structure and circadian regulation may enhance the temporal coordination of ion uptake, long-distance transport, and vacuolar sequestration, thereby promoting ion accumulation without inducing ionic toxicity [13], [23].

Nevertheless, the present results are based on bulk ion measurements, and the underlying regulatory mechanisms remain unresolved. Further studies integrating transporter gene expression, diel ion flux analysis, and compartment-specific ion localization will be required to elucidate how intermittent photoperiods modulate Na⁺ and K⁺ homeostasis in *M. crystallinum*.

E. Implications of Photoperiod Manipulation on Light-Use Efficiency

Light-use Efficiency (LUE) differed significantly among photoperiod treatments despite identical daily light integrals, emphasizing the importance of temporal light–dark distribution in CEA. Intermittent lighting regimes enhanced LUE relative to continuous long-day and short-day conditions, indicating that photoperiod structure influences photon conversion

efficiency beyond total light input. The highest LUE was observed under The 4 h light/4 h dark regime, whereas the 10 min light/10 min dark treatment favored biomass accumulation but showed slightly lower efficiency, suggesting a trade-off between yield maximisation and light-use efficiency. From an engineering perspective, these results highlight intermittent photoperiod manipulation as a practical strategy to improve energy efficiency in plant factories with artificial lighting and other controlled-environment production systems.

E. Overall Integration and Horticultural Implications

Taken together, intermittent photoperiods enhanced several growth parameters relative to continuous short- and long-day lighting, highlighting the role of photoperiod architecture as a tunable control variable in PFAL [14], [38]. The 10 min light/10 min dark regime preferentially increased leaf proliferation. In contrast, the 4 h light/4 h dark regime promoted greater plant height, demonstrating that temporal structuring of light–dark cycles can be aligned with distinct production targets such as canopy density or vertical growth [17], [39]. These results indicate that lighting optimization in PFAL should extend beyond total daily light duration to include the temporal distribution of irradiance [17], [40]. The relative stability of chlorophyll concentration and dry matter percentage across treatments suggests that intermittent photoperiods primarily influenced growth dynamics and biomass partitioning rather than fundamental tissue composition [14], [41].

From a PFAL perspective, this decoupling of morphological control from basic physiological stability is advantageous, as it enables architectural manipulation without compromising product quality attributes [39], [42]. Collectively, the findings support the use of intermittent photoperiod design as a practical strategy for optimizing crop performance and production flexibility in energy-constrained CEA systems [25], [39]. For CEA and PFAL, intermittent photoperiod is a promising management strategy that can maintain plant growth while reducing lighting duration and associated energy demand [25], [40]. Detailed assessments of energy consumption and economic efficiency will, however, be required to fully evaluate its practical advantages under commercial production conditions [38]. Overall, the present findings demonstrate that not only photoperiod length but also the temporal distribution of light–dark cycles influences growth and physiological performance in *M. crystallinum*, consistent with previous reports emphasizing the importance of photoperiod architecture in controlled environments [14], [39]. Future studies integrating CAM-related gas exchange measurements, circadian regulation, and energy-use analysis will further

clarify the mechanistic basis of plant responses to intermittent photoperiods and support evidence-based optimization of PFAL lighting strategies [25], [38].

VI. CONCLUSION

This study demonstrates that temporal structuring of light and dark periods influences growth, canopy development, and nutrient accumulation in *M. crystallinum* under controlled-environment conditions. Intermittent light regimes did not uniformly increase all traits; rather, different architectures of light–dark cycles favored distinct growth outcomes. The 4 h light/4 h dark regime promoted greater plant height, whereas the 10 min light/10 min dark regime enhanced leaf proliferation, indicating that short, frequent alternations particularly stimulate leaf initiation. Dry weight ratio and total chlorophyll content remained relatively stable among light regimes, suggesting that basic tissue composition and photosynthetic pigment levels were largely maintained despite substantial differences in photoperiod structure.

Carbohydrate content was highest under the short-day and 8/8 h intermittent regimes, implying that extended dark periods may facilitate carbon storage processes in this facultative CAM species. Ion accumulation also varied with photoperiod architecture, with the 8/8 h intermittent regime supporting elevated Na^+ and K^+ concentrations, consistent with osmotic adjustment and succulence development characteristic of halophytes. These patterns are compatible with shifts among CAM phases I–IV and associated carbohydrate partitioning, although direct physiological confirmation will require gas-exchange and acidity measurements.

Overall, the findings indicate that not only total day length but also the distribution of light and dark intervals modulates growth and physiological attributes in *M. crystallinum*. Intermittent photoperiod thus represents a promising management option for CEA and PFAL systems, with potential to maintain growth performance while modifying lighting schedules. However, a full assessment of energy-use efficiency, economic performance, and underlying regulatory mechanisms will require further integrative studies that combine CAM dynamics, circadian regulation, and analyses of light-use efficiency.

REFERENCES

- [1] P. Adams et al., "Growth and development of *Mesembryanthemum crystallinum* (Aizoaceae)," *New Phytol.*, vol. 138, no. 2, pp. 171–190, Feb. 1998.
- [2] S. Agaric, "Possibility of desalinization of saline soils by common ice plant (*Mesembryanthemum crystallinum* L.)," *Jpn. J. Trop. Agric.*, vol. 48, pp. 294–298, Dec. 2004.
- [3] S. Agaric et al., "Salt tolerance, salt accumulation, and ionic homeostasis in an epidermal bladder-cell-less mutant of the common ice plant *Mesembryanthemum crystallinum*," *J. Exp. Bot.*, vol. 58, no. 8, pp. 1957–1967, Jun. 2007.

- [4] I. Bouftira et al., "Effect of *Mesembryanthemum crystallinum* extract against DMH-induced colon carcinogenesis in experimental animals," *Int. J. Res. Pharm. Biomed. Sci.*, vol. 3, no. 3, pp. 1038-1043, Jun. 2012.
- [5] I. Bouftira, C. Abdely, and S. Sfar, "Characterization of cosmetic cream with *Mesembryanthemum crystallinum* plant extract: Influence of formulation composition on physical stability and antioxidant activity," *Int. J. Cosmet. Sci.*, vol. 30, no. 6, pp. 443-452, Dec. 2008.
- [6] R. Ksouri et al., "Influence of biological, environmental and technical factors on phenolic content and antioxidant activities of Tunisian halophytes," *C. R. Biol.*, vol. 331, no. 11, pp. 865-873, Nov. 2008.
- [7] S. Agarie et al., "Potential of the common ice plant, *Mesembryanthemum crystallinum*, as a new high-functional food as evaluated by polyol accumulation," *Plant Prod. Sci.*, vol. 12, no. 1, pp. 37-46, Jan. 2009.
- [8] C. Burana, M. Congtrakultien, and N. Kamthorsiriwimol, "A novel study on the growth and development of *Mesembryanthemum crystallinum* (Aizoaceae) in Thailand," *Int. Sci. J. Eng. Technol. (ISJET)*, vol. 4, no. 1, Jan. 2020.
- [9] C. Burana et al., "Effect of packaging materials on the quality and shelf life of fresh-cut vegetables," *Int. Sci. J. Eng. Technol. (ISJET)*, vol. 9, no. 1, pp. 31-36, Jan. 2025.
- [10] M. Osnato et al., "Photoperiod control of plant growth: Flowering time genes beyond flowering," *Front. Plant Sci.*, vol. 12, p. 805635, Feb. 2021.
- [11] V. M. Röber, T. Schmülling, and A. Cortleven, "The photoperiod: Handling and causing stress in plants," *Front. Plant Sci.*, vol. 12, p. 781988, Jan. 2022.
- [12] J. Liu et al., "Novel insights into the factors influencing rhizosphere reactive oxygen species production and their role in polycyclic aromatic hydrocarbons transformation," *Soil Biol. Biochem.*, vol. 198, p. 109562, Nov. 2024.
- [13] L. Bao et al., "Reactive oxygen species-post-translational modifications-central carbon metabolism regulatory loop," *Front. Plant Sci.*, vol. 16, p. 1637328, Sep. 2025.
- [14] S. R. Adams and F. A. Langton, "Photoperiod and plant growth: A review," *J. Hortic. Sci. Biotechnol.*, vol. 80, pp. 2-10, Jan. 2005.
- [15] D. Vince-Prue, "The duration of light and photoperiodic responses," in *Photomorphogenesis in Plants*, R. E. Kendrick and G. H. M. Kronenberg, Eds. Berlin, Germany: Springer, 1986, pp. 269-305.
- [16] G. Harris and J. Griffin, "Flower initiation in the carnation in response to photoperiod," *Nature*, vol. 191, p. 614, Aug. 1961.
- [17] D. D. Avgoustaki, J. Li, and G. Xydis, "Basil plants grown under intermittent light stress," *Food Control*, vol. 118, p. 107389, Dec. 2020.
- [18] A. I. Velez-Ramirez et al., "Plants under continuous light," *Trends Plant Sci.*, vol. 16, no. 6, pp. 310-318, Jun. 2011.
- [19] H. Poorter et al., "The art of growing plants for experimental purposes," *Funct. Plant Biol.*, vol. 39, no. 11, pp. 821-838, Nov. 2012.
- [20] T. Kozai, G. Niu, and M. Takagaki, *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*. London, U.K.: Academic Press, 2016.
- [21] S. L. Harmer, "The circadian system in higher plants," *Annu. Rev. Plant Biol.*, vol. 60, pp. 357-377, Jan. 2009.
- [22] K. Greenham and C. R. McClung, "Integrating circadian dynamics with physiological processes in plants," *Nat. Rev. Genet.*, vol. 16, pp. 598-610, Oct. 2015.
- [23] A. N. Dodd et al., "Plant circadian clocks increase photosynthesis," *Science*, vol. 309, pp. 630-633, Jul. 2005.
- [24] N. Ohtake et al., "Continuous irradiation with alternating red and blue light," *HortScience*, vol. 53, no. 12, pp. 1804-1809, Dec. 2018.
- [25] A. M. Borland et al., "Exploiting the potential of plants with CAM," *J. Exp. Bot.*, vol. 60, pp. 1829-1842, Apr. 2009.
- [26] A. Graf et al., "Circadian control of carbohydrate availability," *Proc. Natl. Acad. Sci. U.S.A.*, vol. 107, no. 20, pp. 9458-9463, May 2010.
- [27] K. Nozue et al., "Rhythmic growth explained by coincidence," *Nature*, vol. 448, pp. 358-361, Jul. 2007.
- [28] E. M. Farré, "The regulation of plant growth by the circadian clock," *Plant Biol.*, vol. 14, pp. 401-410, May 2012.
- [29] Y. Kamiya, "Plant hormones: Versatile regulators," *Annu. Rev. Plant Biol.*, vol. 61, pp. 201-225, Jun. 2010.
- [30] J. W. Chen, K. Patloková, and R. Pokluda, "The effect of daily light integral," *Horticultrae*, vol. 10, no. 3, p. 266, Mar. 2024.
- [31] C. B. Osmond, "Crassulacean acid metabolism," *Annu. Rev. Plant Physiol.*, vol. 29, pp. 379-414, Jun. 1978.
- [32] J. C. Cushman and H. J. Bohnert, "Molecular genetics of CAM," *Plant Physiol.*, vol. 113, pp. 667-676, Mar. 1997.
- [33] K. Winter and J. A. M. Holtum, "Facultative CAM plants," *J. Exp. Bot.*, vol. 65, no. 13, pp. 3425-3441, Jul. 2014.
- [34] L. V. Dever et al., "Molecular regulation of CAM photosynthesis," *Plant J.*, vol. 83, pp. 361-374, Jul. 2015.
- [35] J. Hartwell et al., "Emerging model systems for CAM," *Curr. Opin. Plant Biol.*, vol. 31, pp. 100-108, Jun. 2016.
- [36] B. J. Barkla et al., "Ion transport in halophytes," *Plant Cell Environ.*, vol. 32, pp. 112-128, Feb. 2009.
- [37] R. A. Gaxiola, M. G. Palmgren, and K. Schumacher, "Plant proton pumps," *FEBS Lett.*, vol. 581, no. 12, pp. 2204-2214, 2007.
- [38] T. Kozai et al., "Smart plant factories," *Hortic. J.*, vol. 88, pp. 1-15, May 2019.
- [39] M. Olle and A. Viršile, "Effects of LED lighting," *Agric. Food Sci.*, vol. 22, no. 2, pp. 223-234, Jan. 2013.
- [40] C. A. Mitchell et al., "Light-emitting diodes in horticulture," *Hortic. Rev.*, vol. 43, pp. 1-87, Sep. 2015.
- [41] H. Dou et al., "Responses of leafy vegetables to dynamic light," *Sci. Hortic.*, vol. 235, pp. 273-280, Jun. 2018.
- [42] G. Pennisi et al., "Optimal light intensity for indoor cultivation," *Sci. Hortic.*, vol. 272, p. 109508, Oct. 2020.



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