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Research Article

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Variation of CO_2 Concentration in Greenhouses and Effects on Growth and Yield in *Alstroemeria* with CO_2 Supplementation

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Abstract

We analyzed the variations in the CO_2 concentration and temperature between a CO_2-enriched and control greenhouse. We cultivated *Alstroemeria* 'Hanhera' in the two greenhouses and assessed the growth parameters (stem length, stem thickness, and the number of flowers) and yield. The CO_2-enriched greenhouse had a CO_2 generator that produced CO_2 at rate of 0.36 kg/h and its windows were programmed to open when the temperature exceeded 20°C and close when it dropped below 15°C. The control greenhouse had no additional CO_2 supplementation, and its windows were programmed to open when the temperature exceeded 20°C and close at approximately 17:00. In the morning, CO_2 concentration remained above 500 ppm in the CO_2-enriched greenhouse, which was higher than that in the control greenhouse (approximately 370 ppm). The ventilation effect only through the side windows to reduce the temperature in both greenhouses did not appear dynamically. CO_2 supplementation promoted plant growth, resulting in a significant increase in plant yield of over 60% compared to that of the control greenhouse. Our findings suggest that elevated CO_2 concentration in the morning can significantly promote the growth and development of *Alstroemeria* during the winter.

Key words: Controlled environment agriculture, Elevated CO_2, Growth

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Introduction

Protected horticulture has gained significant interest due to ongoing climate changes Greenhouses, because of their enclosed environment, face difficult atmospheric conditions and nutritional factors. Therefore, creating an appropriate greenhouse environment is crucial for improving crop productivity. Carbon dioxide (CO_2) is essential for the growth and development of plants. In a greenhouse, limiting the concentration of CO_2 has negative impacts on crops. To overcome this problem, by supplying additional CO_2 artificially, which is called 'CO_2 enrichment', cultivator can create environment in which the photosynthetic activity of crops can flourish. Numerous studies have examined the relationship between plant growth and CO_2 concentration [1,2]. Fan et al. have demonstrated that elevated CO_2 concentration enhances plant growth under water stress by increasing leaf photosynthesis in bell pepper [3]. Zheng et al. found that leaf biochemical and photochemical processes are crucial in determining the positive effect of CO_2 enrichment. These processes directly increase carboxylation rates and electron transport rates in perennial grasses [4]. It was found that CO_2 enrichment in greenhouses significantly improved the quality and increased the yield of cherry tomatoes (*Lycopersicon esculentum* L.) [5]. However, Cubillos and Hughes found that elevated CO_2 had few significant effects on tomatoes (*Lycopersicon lycopersicum*) [6]. Additionally, the impact of CO_2 enrichment on plant growth, yield, and flower stem quality is greatly influenced by temperature and supplementary light [7-9]. Pereyda-González et al. found that elevated CO_2 counteracted the detrimental effects of high temperatures on growth parameters and flower number in peppers. However this was not enough to prevent flower abortion and the detrimental morphological characteristics of fruit caused by a temperature of 40°C [10]. In addition, photosynthesis is enhanced by CO_2 enrichment, and lateral branch and floral bud production are maximized at the high light level (260 ± 40 μmol m^{-2} s^{-1}) used here in *Phalaenopsis* Queen Beer 'Mantefon' [11]. In order to obtain the positive CO_2 enrichment, several factors such as temperature, light, and species must be taken into account.

Alstroemeria is a type of cut flowers that can be grown in South Korea. *Alstroemeria* is found in countries with cool climates, as it requires low temperature for optimal growth and production [12,13]. In South Korea, farmers can economically benefit from this characteristic by using protected cultivation techniques during the winter months (December to February) in South Korea). In the systematized korean floriculture industry, there is ongoing adoption of CO_2 enrichment. However, there has been insufficient research on the effects of CO_2 enrichment on plants, particularly *Alstroemeria* Korean cultivar.

In this study, we examined the difference in CO_2 concentration between greenhouses with and without additional CO_2 supplementation on a field scale, not lap scale. The temperature changes within the greenhouses due to ventilation were verified. We examined the impact of supplementary CO_2 on the growth condition and productivity of *Alstroemeria* 'Hanhera'.

Materials and Methods

Plant materials and experimental design

The experiment took place at Chonnam University in Gwangju, South Korea, using two greenhouses: a control greenhouse and a CO_2-enriched (35°09′35″ N, 126°51′11″ E). Each greenhouse (5 m × 15 m × 3 m) was equipped with an Inner-Greenhouse (IG) (0.8 m × 10 m × 2 m) inside to protect plants from freezing (Fig. 1).

We used *Alstroemeria* 'Hanhera', which were cultivated on a plastic box (0.52 m × 0.37 m × 0.32 m). Twenty-one *Alstroemeria* 'Hanhera' with 4-5 shoot were pruned leaving 10 cm shoot part and transplanted with 20 cm gap apart (Row: 3, Column: 7) (Fig. 1) on soil on 08.25.2021. A first cut net (1.2m × 10 m × 0.30 m) and a second cut net (1.2m × 10 m × 0.80 m) was installed (Fig. 1). The drip-irrigation system ran for 5-7 minutes twice weekly. The electric heater (Changsung boiler, South Korea) was used from 18:00 to 05:00, but

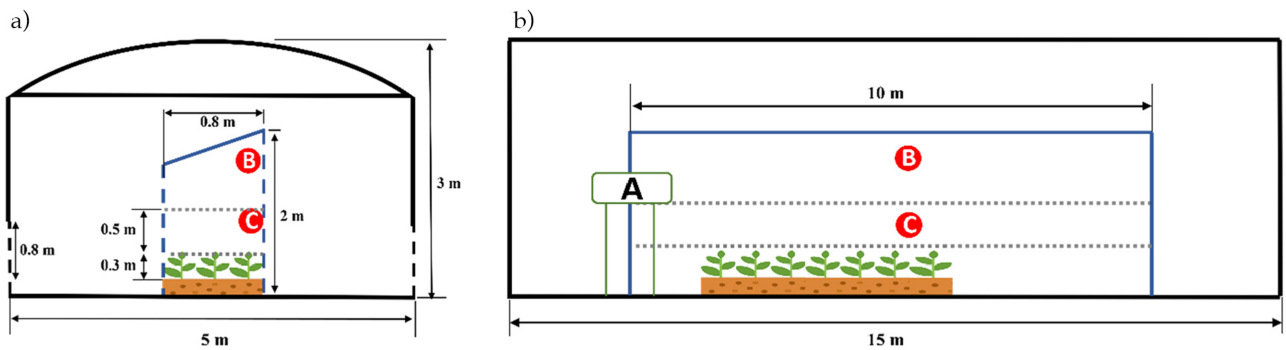

Fig. 1. Schematic of the greenhouse. The side windows are indicated by black dash lines (– –) and the blue dash lines (– –) represent the windows of IG. The gray dot lines (···) represent cut nets. The red circle 'B' represents temperature sensors and the red circle 'C' represents CO_2 sensor. a) The front schematic. b) The side schematic. 'A' represents the CO_2 generator.

it was switched off when the temperature exceeded 15°C.

The side windows of the control greenhouse were manually opened when temperature was above 20°C and closed around 17:00. On the other hands, the side windows of the CO_2-enriched greenhouse were automatically adjusted when the temperature exceeded 20 °C and closed when it dropped below 15°C.

The windows of IG in both greenhouses were opened since 01.20.2022. The windows of IG in the control greenhouse were opened approximately every 9:00 and closed around 17:00, which was likely the same time as when the side windows were manually closed. On the other hands, the windows of IG in the CO_2-enriched greenhouse were automatically manipulated, when the temperature exceeded 10°C and the CO_2 concentration surpassed 600 ppm. However, when the temperature exceeded 20°C, they were opened regardless of the CO_2 concentration being below 600 ppm. And they were closed when the side windows were closed. Additionally, when the temperature was under 10°C, they were closed without exception.

Ventilation system in the CO_2-enriched greenhouse was controlled by an environment controller (DAONRS Inc., South Korea).

A CO_2 generator (DAONRS Inc., South Korea) was installed in the CO_2-enriched greenhouse (Fig. 1b). The generator operated 0.36 kg/h of CO_2. Here is the time to operate the CO_2 generator

- 12.03.2021-12.14.2021
  5:30-18:00 with twice rest time (09:00-09:30, 12:30-13:00)
- 12.15.2021-01.23.2022
  5:30-16:00 with once rest time (12:00-13:00)
- 12.24.2022-02.28.2022
  5:30-12:00

Data measurement and storage

We utilized a temperature sensor (PT100 RTD, Deajin Sensor Electric Works, South Korea) and a CO_2 sensor (CM1107, CUBIC, China) (Fig. 1) to measure temperature and CO_2 concentration. DAONi-con (DAONRS Inc., South Korea) was used to store these data at 1-minute intervals.

Analysis of growth parameters and marketable yield

Plant growth parameters, including stem length, stem thickness, and the total number of flowers, were measured twice a week from 04.08.2022 (the first day of flowering after the CO_2 enrichment) to 04.26.2022. The length of the stem was measured from ground to shoot apex. The stem thickness was measured beneath the inflorescence. The number of flowers per stem was counted at the start of anther dehiscence. In addition, the marketable yield of cut flowers was investigated from 04.07.2022 to 05.20.2022.

Statistical analysis

Excel (Version 16, Microsoft 365, USA) was used for data analysis. The temperature and CO_2 concentration were plotted with every 10 minutes without any noise. The growth parameters were presented as mean ± standard deviation and determined t-test (p=0.05).

Results and Discussion

CO_2 concentration and temperature in a control greenhouse and a CO_2-enriched greenhouse

The CO_2 concentration in the CO_2-enriched greenhouse remained consistently higher than the control greenhouse, regardless of factors such as window opening or photosynthesis during the daytime (Table 1). The CO_2 concentration decreased in the morning in greenhouses (Fig. 2). Fig. 3 showed the CO_2 concentration changes under typical weather. In the CO_2-enriched greenhouse, the CO_2 concentration rapidly increased and decreased between approximately 6:00-10:00, even though the windows were not opened (Fig. 3). On the overcast day, CO_2 concentration did not decrease in the CO_2-enriched greenhouse during the morning (Fig. 4). This implied a decrease in photosynthesis as well as stomatal aperture. Tagawa et al. found that increasing the CO_2 concentration can enhance the photosynthetic rate, even under low light conditions similar to dark cloudy weather in a winter

Table 1. The average of CO_2 concentration in the control greenhouse and CO_2-enriched greenhouse

	Control greenhouse	CO_2-enriched greenhouse
The average during total experiment period (ppm)	378.00 ± 37.95[1)]	410.07 ± 141.13[2)]
Only day time 6:00-18:00 (ppm)	371.84 ± 38.29[3)]	464.28 ± 178.12[4)]

Values represent mean ± standard deviation.
1) n=11,615; 2) n=11,284; 3) n=5,787; 4) n=5,613.

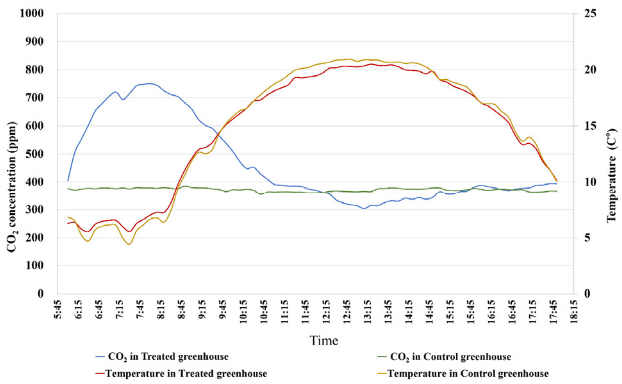

Fig. 2. The day time (06:00-18:00) CO_2 concentration and temperature average in the control greenhouse and the CO_2-enriched greenhouse.

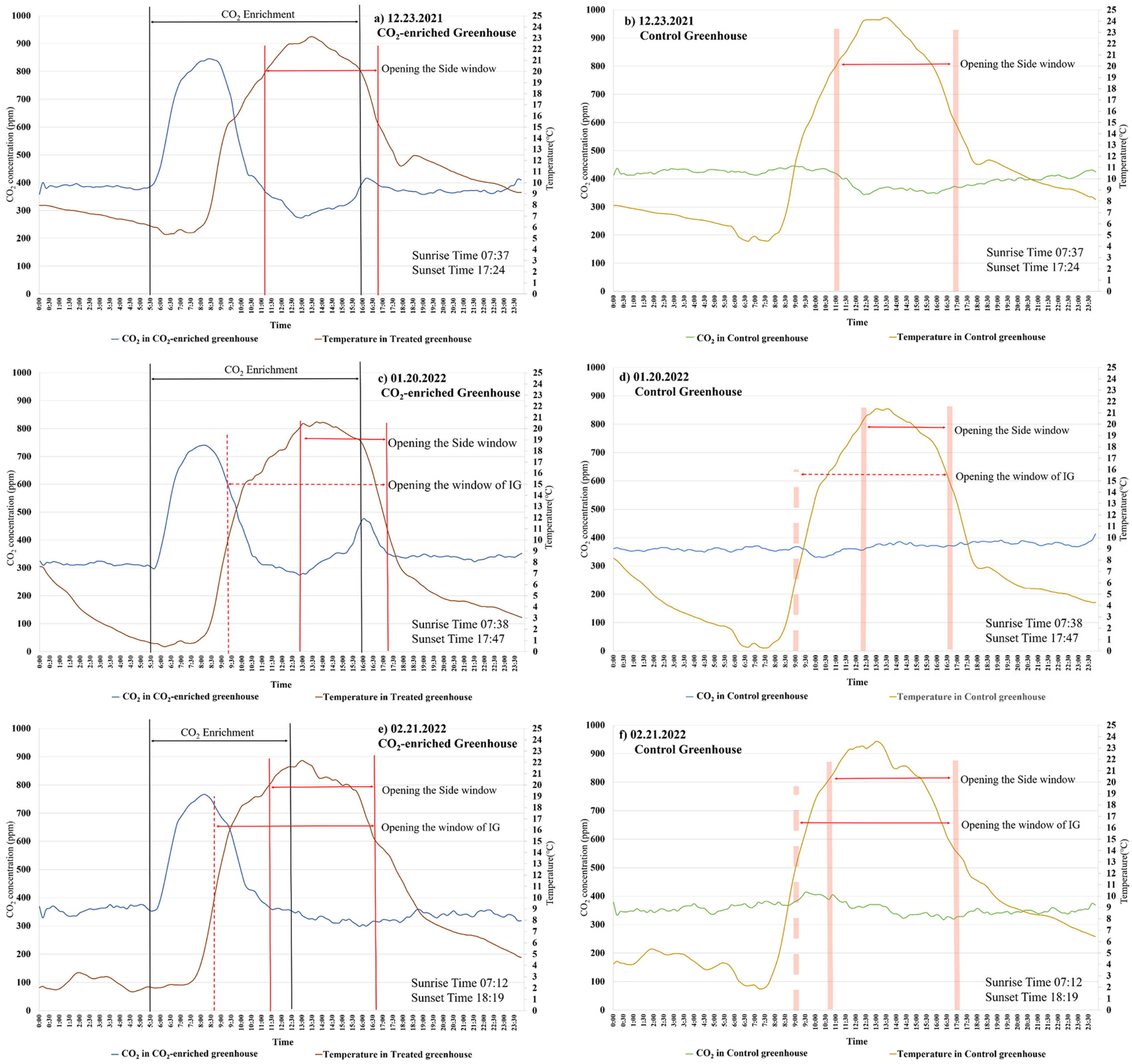

Fig. 3. The CO_2 concentration and temperature change in greenhouses (CO_2-enriched greenhouse and control greenhouse) under typical weather. a) 12.23.2021 in the CO_2-enriched greenhouse; b) 12.23.2021 in the control greenhouse; c) 01.20.2022 in the CO_2-enriched greenhouse; d) 01.20.2022 in the control greenhouse; e) 02.21.2022 in the CO_2-enriched greenhouse; f) 02.21.2022 in the control greenhouse.

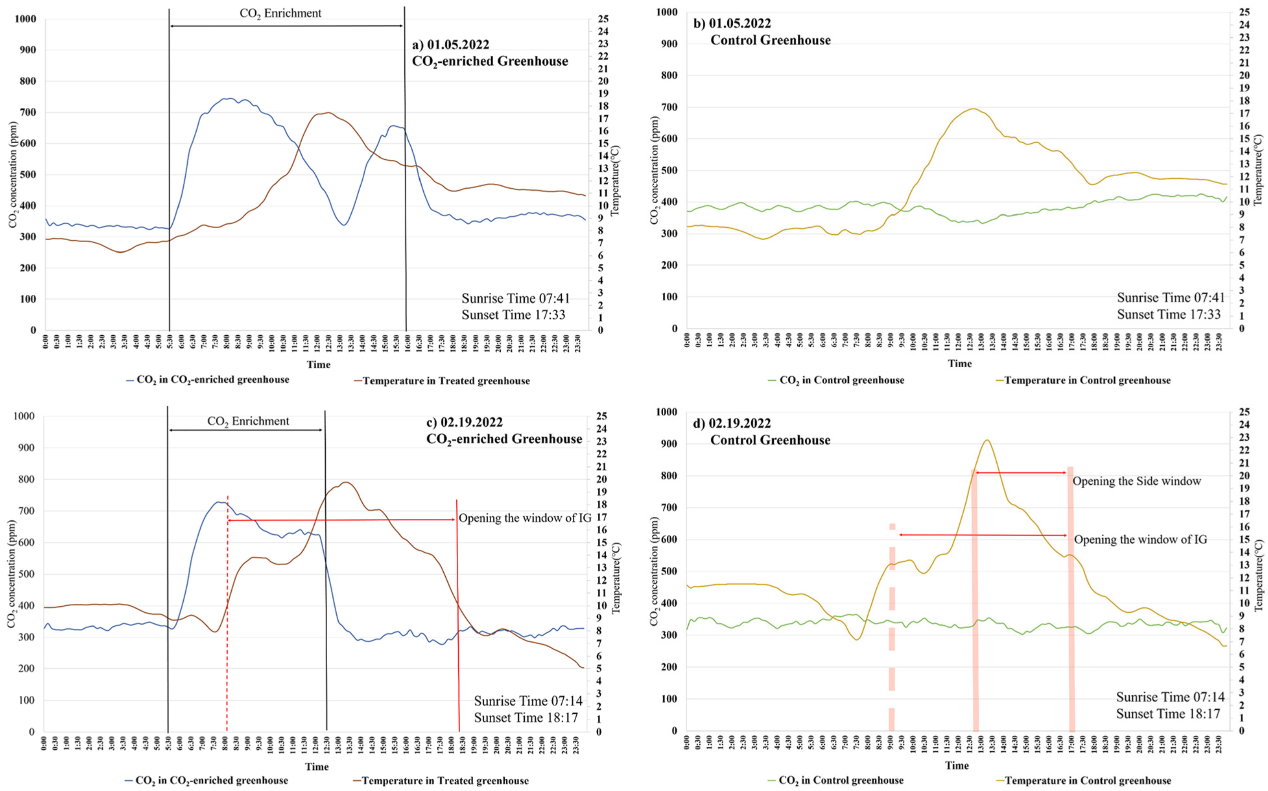

Fig. 4. The CO_2 concentration and temperature change in greenhouses on overcast days. a) 01.05.2022 in the CO_2-enriched greenhouse; b) 01.05.2022 in the control greenhouse; c) 02.19.2022 in the CO_2-enriched greenhouse; d) 02.19.2022in the control greenhouse.

greenhouse [14].

The temperature changes in both greenhouses showed similar trends (Figs. 2-4). Temperature is crucial for plant growth. In this study, natural ventilation was achieved by using only side windows (roll-up type) to restrain temperature increase. However, the immediate impact of temperature reduction through natural ventilation was found to be insignificant in this study (Fig. 3, Figs. 4c, 4d). The environmental changes in the greenhouse caused by natural ventilation are influenced by factors such as the structure of the greenhouse, wind direction, and other relevant factors [15-17]. Kacira et al. found that highest greenhouse ventilation rates were achieved when both roll-up type side windows and roof vents were fully open, while merely opening side windows, regardless of the type of the side window, resulted in a low ventilation rate [17]. According to the report, it is expected that the temperature did not decrease significantly when only side windows were used for ventilation.

Plant growth responses and marketable yield between the control greenhouse and the CO_2-enriched greenhouse

The growth parameters exhibited significant improvements in the CO_2-enriched greenhouse (Table 2). The stem length showed the most significant change, increasing by 43.23% ($p<0.001$) (Table 2). This may af-

Table 2. Growth parameters of *Alstroemeria* grown under two greenhouses: Control greenhouse and CO_2-enriched greenhouse

	Control greenhouse[1)]	CO_2-enriched greenhouse[2)]	% increase	*P-value*
Stem length (cm)	65.28 ± 9.01	93.50 ± 21.49	43.23	$p<0.001$
Stem thickness (mm)	6.02 ± 1.50	6.66 ± 1.68	10.63	0.005
The total number of flowers	11.90 ± 4.41	14.80 ± 5.31	24.37	$p<0.001$

Values represent mean ± standard deviation.
1) n=172; 2) n=72.

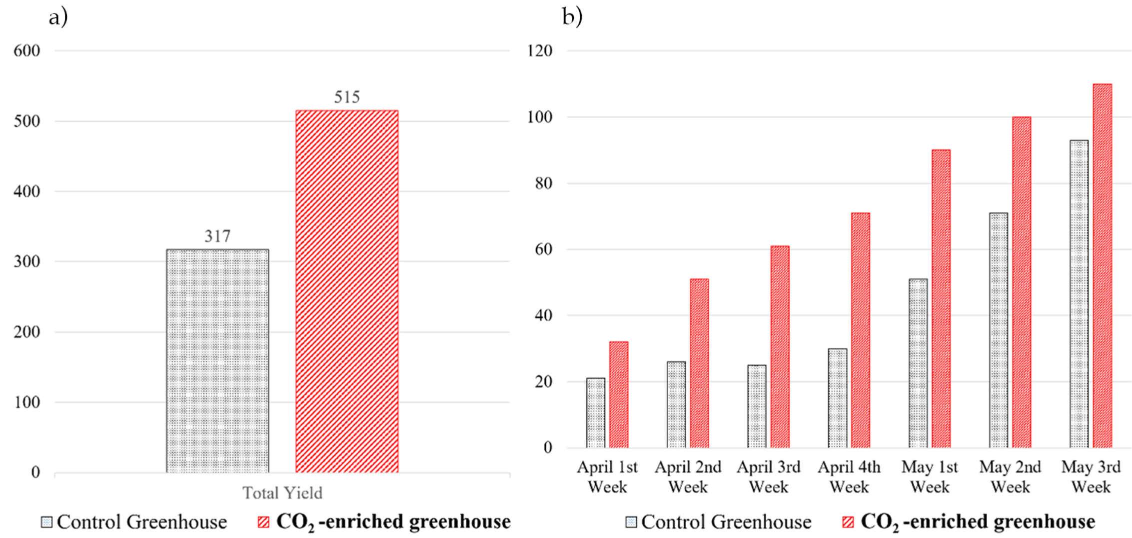

Fig. 5. The Plant yield. a) Total yield; b) Weekly yield.

fect profits from crops since the longer the plant length is, the higher the product value is. The stem thickness increased by 10.63% (Table 2, p=0.005). Similar findings were observed in other species such as roses, *Gerbera jamesonii*, and *Phalaenopsis* [18-21]. In addition, the average of number of flowers per flowering shoot in the CO_2-enriched greenhouse was approximately 15, which was increased by 24.37% (Table 2, p<0.001). The most significant outcome was the marketable yield, as shown in Fig. 5. Fig. 5a illustrates the disparity of total marketable yield between two greenhouses. The marketable yield in the CO_2-enriched greenhouse was 62.46% higher than in the control greenhouse. Additionally, weekly plant yields were consistently higher in the CO_2-enriched greenhouse (Fig. 5b). The difference was especially noticeable in the early stages of harvesting (Fig. 5b). The results suggest that harvesting high-quality crops early in CO_2-enriched greenhouse can result in economic advantages. Xu et al. found that the flower production of *G. jamesonii* were barely promoted about 1 flower per plant under CO_2 enrichment in, the flower yield of each plant was averagely increased [20]. On the other hand, in case of *Phalaenopsis* 'Fuller's 'Pink Swallow', CO_2 enrichment had no effect on the number of flowers [21].

The effects of elevated CO_2 on flowering time are not as well understood and vary widely among species [2]. In the present study, elevated CO_2 concentration environment did not have a significant impact on the flowering time of *Alstroemeria*. It was found that high CO_2 concentration could accelerate flowering time in long-day species and delay flowering in short-day species [22]. Additionally, Song et al. found that flower induction may either speed up or delay flowering, depending on the photoperiod [23]. *Alstroemeria* is a long day plant, but its flowering time may be influenced by temperature [12].

In fact, it is not cost-efficient to use supplementary CO_2 for *Alstroemeria* due to high ventilation rate required by its temperature requirements. However, in winter, low temperature areas such as South Korea may benefit from shorter ventilation times for efficient management. Particularly, it is anticipated that economic management can be achieved by installing an additional greenhouse on a bank like IG and supplying CO_2 based on temperature and time dependencies to maintain high CO_2 concentration before activating the ventilation system (likely in the morning during winter) in a real field.

Conclusion

In practical settings, it is challenging to maintain a consistently high CO_2 concentration during the morning on clear days because of photosynthetic activity of the plants. However, it is clear that maintaining a CO_2 concentration of 500 ppm or higher during the morning alone can greatly enhance plant growth and productivity. The ventilation through the side windows did not effectively reduce the temperature.

In the next study, an actual profit analysis will be conducted, and economically viable supplementary CO_2 methods will be proposed based on the results.

Note

The authors declare no conflict of interest.

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