Influence of gibberellic acid on the physiology and flower quality of gerbera and lily cut flowers

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Abstract

Y.A. Othman, M.G. Al-Ajlouni, T.A. A’saf, H.A. Sawalha, and M. Bany Hani. 2021. Influence of gibberellic acid on the physiology and flower quality of gerbera and lily cut flowers. Int. J. Agric. Nat. Resour. 21-33. The objective of this study was to assess the influence of different foliar gibberellic acid (GA₃) levels (0, 10, 50, and 200 mg L⁻¹) and application timing on the growth, physiology (chlorophyll and gas exchange) and flower quality of gerbera (Gerbera jamesonii cvs. Beaudine and Palm Beach) and Asiatic lily (Lilium × elegans cvs. Fangio and Eldivo). The application of GA₃ (50 mg L⁻¹) increased (p<0.05) gerbera shoot height (30%), pedicel length (20%), and vase life (12.5%) and decreased the number of days to flowering (7%) compared to the control. GA₃ application at the seedling stage increased pedicel length and flower diameter compared to GA₃ treatment at the flower initiation stage. However, the chlorophyll content index, photosynthesis (Pn), stomatal conductance (gs) and transpiration (E) were similar across the study period. For Asiatic lily, 10 and 50 mg L⁻¹ were the best GA₃ levels in terms of leaf gs, E and flower diameter. Compared to 0, 10 and 50 mg L⁻¹-GA₃, 200 mg L⁻¹-GA₃ decreased the number of days to flowering. Overall, the application of 50 mg L⁻¹-GA₃ to gerbera and lily cultivars at the seedling stage can potentially improve flower quality and shorten the number of days to flowering.

Keywords: Chlorophyll, GA₃, hormone, photosynthesis, vase life, SPAD.

Introduction

Plant growth regulators (PGRs) have been recognized globally for their ability to support efficient and intensive plant production while conserving water and nutrients. This is because PGRs, specifically GA₃, induce growth and yield (Ayad et al., 2018; Celis-Arámburo et al., 2011). For example, foliar application of GA₃ (50 mg L⁻¹) to strawberry decreased the time needed to flowering and increased Pn, gs, E and yield compared to the untreated control. This dynamic feedback process allows the plant to extract available soil resources, on which it is completely dependent (Celis-Arámburo et al., 2011). Long-distance signals established in the root (upwards signals) can trigger an early warning in the shoot of fluctuations in...
external nutrient availability, while downwards signals (shoot to root) are necessary to ensure that both root physiology and development are integrated with the nutritional demands of the shoot (Forde, 2002). These signals that translocate between plant organs are mediated by nutrients or PGRs (López-Bucio et al., 2003). Plant growth regulators such as auxins, cytokinins, gibberellins and ethylene are a wide group of chemical compounds that can modify plant development processes, including root growth and plant nutrition (López-Bucio et al., 2003; Pérez-Jiménez et al., 2015). The response of plants to environmental variables such as light, pathogens, temperature and soil nutrition is closely linked to PGRs (Kiba et al., 2011).

Gibberellins such as GA$_3$ play a key role in hormonal and nutrient regulation and flowering (Pérez-Jiménez et al., 2015; Tiwari et al., 2012). GA$_3$ stimulates the redistribution of photosynthates (regulates sink–source relationships), specifically the transportation of photosynthetic products from leaves to buds (Iqbal et al., 2011; Wen et al., 2018). In the hybrid lily (Lilium longiflorum cv. Casa Blanca), the endogenous GA$_3$ concentration is low in daughter scales at early growth stages but then dramatically increases during bulb maturation after flowering (Kim & Kim, 2005). Exogenous application of GA$_3$ (200 mg L$^{-1}$) on Ceylon Rock Primrose (Henckelia humboldtiana) reduced the number of days to flowering and increased the number of inflorescences per plant (10.9 ±1.8) compared to untreated plants (Sumanasiri et al., 2013). The application of exogenous GA$_3$ spray at 200 mg L$^{-1}$ inhibited the effects of growth retardants (uniconazole) on shoot growth and flower induction (Jiao et al., 1991). However, the application of PGRs (specifically, GA$_3$) could result in extreme pedicel elongation and bent neck problems (physiological disorders in gerbera), which significantly reduce the marketable value of cut flowers. Several studies have been conducted to evaluate the proper GA$_3$ level and application frequency during seedling or at postharvest (on cut-stems in preserving solution) stages, including gerbera and lily (Mehraj et al., 2013; Ranwala & Miller, 2002). However, few studies have included leaf gas exchange analysis [photosynthesis (Pn), stomatal conductance (gs) and transpiration (E)] as an aid to determine the optimal level for gerbera and lily flower components. In addition, no study has assessed the effect of GA$_3$ application timing (seedling vs. flower initiation stage) on flower quality in gerbera. We hypothesized that the application of GA$_3$ at the seedling stage can increase the time window for pedicel growth and increase the probability for extreme pedicel growth, which might lead to less lignification of vascular elements in the pedicel. Foliar application of GA$_3$, at the beginning of the flower induction stage could improve flower size and number and reduce the probability of bent neck problems at the postharvest stage. In addition, we believe that exogenous foliar application of GA$_3$ will improve lily flower quality components (stem length and diameter and flower diameter, number, and vase life). The main goal of this research was to develop cultural system practices that increase water and nutrient use efficiency by improving flower quality components and reducing the growing season interval (i.e., reduce the number of days from transplanting to harvesting). To achieve this goal, our objective was to evaluate the influence of different exogenous GA$_3$ levels (0, 10, 50, and 200 mg L$^{-1}$) and application timing (transplanting and flower initiation stages) on the growth, leaf-level physiology (chlorophyll content index, and gas exchange) and flower quality of two gerbera and Asiatic lily cultivars. Information from this study will be valuable to better understand and develop efficient culture systems that increase flower yield, quality and input cost for gerbera and lily cut flower growers.

Materials and Methods

Site description and plant material

The experiments were carried out in a greenhouse at the Department of Horticulture and Crop Science,
University of Jordan, Amman, Jordan, between March and September 2019. Two gerbera [Gerbera jamesonii cvs. Beaudine (red) and Palm Beach (yellow)] and Asiatic hybrid lily [Lilium × elegans cvs. Fangio (pink) and Eldivo (yellow)] cultivars were used. Both gerbera seedlings (8 weeks old) and lily bulbs (1 year old) were transplanted into 7 L pots filled with growing medium (3:1 peatmoss-perlite). Irrigation was conducted manually twice a week. Temperatures and light intensity during the study period are given in Figure 1.

**Gibberellic acid (GA) treatment**

Four different foliar GA$_3$ (4%, CP Bio, Inc., Chino, CA) levels (0, 10, 50, and 200 mg L$^{-1}$) and two application timings (transplant and flower initiation stage) were used for the gerbera experiment. The total volume of foliar GA$_3$ solution (or water for the control) applied to each plant was 50 mL per spray. For application timing, the first application timing treatment was at the seedling stage ($4^{th}$ leaf stage, six weeks after transplanting), while the second timing treatment for the untreated set of gerbera plants was at the flower initiation period. In both timing treatments, foliar GA$_3$ levels were applied twice (10-day interval) following the procedure of Leskovar & Othman (2018). Plants under control conditions were sprayed with tap water only. For the lily experiment, four GA$_3$ levels (0, 10, 50, and 200 ppm) were applied twice (10-day interval) at the seedling stage ($4$-leaf stage, approximately 20 days after planting).

**Leaf-level physiology and flower quality**

The leaf-level chlorophyll content index (SPAD) and gas exchange ($P_n$, $g_s$, and $E$) for both gerbera and lily cultivars were measured at the flowering stage. Both SPAD and gas exchange measurements were conducted between 11:00 a.m. and 1:00 p.m. in two fully mature and sun-exposed leaves. The chlorophyll content index (SPAD) was determined using a chlorophyll meter (CCM-200 plus; Opti-Science Inc., Hudson, NH, USA), and gas exchange was measured with a portable photosynthesis system (LI-6400XT; LI-COR, Lincoln, NE, USA) following the procedure of Othman *et al.* (2015).

Flower quality variables (stem (pedicel) length and diameter, number of days to flowering, flower...
diameter, number per plant (gerbera)/stem (lily) and vase life) were determined during the flowering stage. The number of days to flowering was from the day of planting (day 1) to the blooming of the first bud on each stem (plant) (Al-Ajlouni et al., 2017a). At the flowering stage, both gerbera and lily flowers were harvested for vase life determination. Following commercial practices, gerbera harvesting was performed when the outer 2 rows of petal discs were open. Lily stems were harvested when one of the flower buds began to open but was not fully opened. Vase life was determined for gerbera flowers by measuring the number of days from harvesting day to the first 3 petals falling off or when the flower pedicel bent (bent neck problem). For the lily, vase life was from harvesting day until the first lily flower/per stem had fallen off or wilted.

**Experimental design setup and statistical analysis**

A randomized complete block design (RCBD) with four replicates and three factors (2 cultivars, 4 GA$_3$ levels and 2 application timing) was used for the gerbera experiment. For the lily experiment, RCBD with two factors (2 cultivars and 4 GA$_3$ levels) and four replications was used. In both experiments, analysis of variance (ANOVA) and Tukey’s HSD test (P≤0.05) in SAS (Version 9.2 for Windows; SAS Institute, Cary, NC) were used to identify differences between treatments and their interactions.

**Results and Discussion**

Cut flower production is a growing business worldwide, including Jordan. Growers apply intensive fertigation programs to produce superior flowers, which raises substrate salinity and input costs. The application of PGRs such as GA$_3$ and benzyladenine has been recommended to improve cut flower yield and quality (vase life) and reduce management input costs (Danaee et al., 2011; Vieira et al., 2010). For example, Naranja & Balladares (2008) found that foliar application of GA$_3$ (50 mg L$^{-1}$) to perennial aster (Aster ericoides) 30 days after planting increased stem length and shoot mass compared to untreated flowers. In this study, foliar GA$_3$ had a slight impact on gerbera growth and leaf-level physiology, specifically plant height (Table 1). The GA$_3$ (10, 50 and 200 mg L$^{-1}$) application increased plant height by approximately 30% compared to the control. Gibberellic acid increases plant growth and source potential by promoting fructose-1,6-bisphosphatase and sucrose phosphate synthase and stimulating phloem loading (Iqbal et al. 2011). A recent study revealed that GA is a key modulator of internode elongation (Chen et al., 2020). When sugarcane seedlings were sprayed with 200 mg L$^{-1}$ GA$_3$, pathways and biosynthesis of secondary metabolites, plant hormones, and cell wall components were enriched in the internodes of the GA-treated plants (Chen et al., 2020).

Photosynthesis plays a key role in plant growth, development and productivity and can be significantly affected by management practices such as irrigation, nutrients and hormonal application (Othman et al., 2014; Tadros et al., 2021; Wen et al., 2018). In addition, chlorophyll content in the leaves is critical because these pigments provide the required reaction energy for the photosynthesis process by absorbing energy from the light (Wen et al., 2018). Endogenous GA increases chlorophyll pigments in the leaf by increasing the numbers and sizes of chloroplasts (Arteca, 1996). Gibberellin promoted chloroplast biogenesis in rice (Oryza sativa) as a means to maintain the chloroplast population of expanded cells (Jiang et al., 2012). In that study, chloroplast division was potentially decreased in GA-deficient mutants of rice, d18-AD (Jiang et al., 2012). The 100 mg L$^{-1}$ dose of GA$_3$ increased the total chlorophyll content of Camellia oleifera by 100.00% and Pn by 59.55% compared to the control (Wen et al., 2018). However, in this study, no significant differences between GA$_3$ levels were found in chlorophyll content index (SPAD) and leaf-level gas exchange [Pn, gs and E (Table 1)]. In addition, SPAD and gas exchange
Table 1. Plant height, chlorophyll content index (SPAD), photosynthesis ($P_n$), stomatal conductance ($g_s$), and transpiration ($E$) of gerbera flowers (red ‘Beaudine’; yellow ‘Palm Beach’) grown in the greenhouse under different gibberellic acid application rates and application times (transplanting and flower induction stages).

| GA$_3$ rate (R) mg L$^{-1}$ | GA$_3$ application timing (T) | Cultivar (CV) | Plant height (cm) | SPAD | $P_n$ (µmol m$^{-2}$ s$^{-1}$) | $g_s$ (mol m$^{-2}$ s$^{-1}$) | $E$ (mmol m$^{-2}$ s$^{-1}$) |
|-----------------------------|------------------------------|----------------|-------------------|------|--------------------------|-----------------|-----------------|
| Control (0)                 |                               |                | 42.5 b            | 54.1 | 15.0                     | 0.113           | 3.47            |
| 10                          |                              |                | 56.5 a            | 54.7 | 15.2                     | 0.111           | 3.45            |
| 50                          |                              |                | 55.3 a            | 53.2 | 15.3                     | 0.130           | 3.90            |
| 200                         |                              |                | 54.4 a            | 49.3 | 15.1                     | 0.131           | 3.87            |
| Transplant                  |                              |                |                   |      |                          |                 |                 |
| Flowering                   |                              |                |                   |      |                          |                 |                 |
| Beaudine                    |                              |                | 56.1              | 52.0 | 14.9                     | 0.125           | 3.77            |
| Palm Beach                  |                              |                | 54.7              | 52.8 | 15.4                     | 0.123           | 3.71            |
| P-value                     | R                            |                | $.0001            | 0.104| 0.9665                   | 0.3839          | 0.4853          |
|                             | T                            |                | 0.1548            | 0.6945| 0.3539                   | 0.8825          | 0.8307          |
|                             | R×T                          |                | 0.1341            | 0.9381| 0.2079                   | 0.0022          | 0.0036          |
|                             | CV                           |                | 0.0524            | 0.0479| 0.0192                   | 0.2146          | 0.1753          |
|                             | R×CV                         |                | 0.7852            | 0.0422| 0.9792                   | 0.9403          | 0.9234          |
|                             | T×CV                         |                | 0.8657            | 0.9403| 0.5443                   | 0.4863          | 0.2846          |
|                             | R×T×CV                       |                | 0.9254            | 0.016 | 0.2667                   | 0.2192          | 0.159           |

Values in columns followed by different letters indicate significant differences between treatments according to Tukey’s HSD test (P≤0.05).

were similar across GA$_3$ levels (0, 10, 50, 200 mg L$^{-1}$). However, there was a significant GA$_3$ rate × application timing × cultivar interaction for SPAD as well as in the GA$_3$ rate × application timing interaction for $g_s$ and $E$ (Table 1, Figures 2 and 3). The SPAD interaction results revealed that the ‘Beaudine’ cultivar consistently had the lowest SPAD across the GA$_3$ rate and over the application timing (Figure 2). Additionally, the control treatment had a SPAD similar to the SPAD of the GA$_3$-treated plants (Figure 2). For $g_s$ and $E$, GA$_3$ rate × application timing was significant for the ‘Palm Beach’ cultivar only (Figure 3). The 10 and 200 mg L$^{-1}$ GA$_3$ at the transplanting stage and 50 mg L$^{-1}$ GA$_3$ at the flowering stage and the control had the highest $g_s$ and $E$. Overall, the leaf-level physiological response of gerbera cultivars to GA$_3$ application was not significant or consistent.

Figure 2. Chlorophyll content index (SPAD) of gerbera flowers (red ‘Beaudine’; yellow ‘Palm Beach’) grown in the greenhouse under different gibberellic acid (GA3) application rates and application times (transplanting and flower induction stages). Different letters above bars indicate significant differences between treatments according to Tukey’s HSD test (P≤0.05).
Flower quality variables such as color, size, number per plant and vase life can potentially influence commercial cut flower appearance and marketing (Burchi et al., 2010; Woodson, 1991). Exogenous application of PGRs (e.g., GA₃), nutrient management, growing substrate, and cultivar breeding can potentially improve cut flower growth and quality (Burchi et al., 2010; Al-Ajlouni et al., 2017b, Ayad et al., 2019). Sumanasiri et al. (2013) concluded that GA₃ (200 mg L⁻¹) can be used to improve flower quality, appearance and, consequently, marketing value for Ceylon Rock Primrose flowers. GA₃ promotes transitions from meristem to shoot growth, juvenile to adult leaf stage, vegetative to flowering, and stimulates pedicel growth (Gupta & Chakrabarty, 2013). In our study, exogenous foliar application of GA₃, application timing, cultivar and their interaction had a significant effect on flower quality components of gerbera (Table 2, Figure 4). The plants with 50 mg L⁻¹ GA₃ treatment had a higher pedicel length and vase life than the control (Table 4). In addition, the GA₃ rate × application timing × cultivar interaction for pedicel length showed that the control and the 10 mg L⁻¹-GA₃ application at flowering were shorter than other treatments for both cultivars (Figure 4). However, no significant differences were found in pedicel diameter, flower diameter, or flower yield across GA₃ levels (0, 10, 50, 200 mg L⁻¹). In terms of cultivars, the ‘Beaudine’ cultivar had a higher pedicel diameter and vase life and a lower yield (flower number per plant) than the ‘Palm Beach’ cultivar (Table 2). The interaction analyses for pedicel length and flower diameter for both cultivars were mostly similar across GA₃ rate and application timing (Figure 4). In gerbera, extreme pedicel growth can increase the probability of less lignification of vascular elements and lead to bent neck. This
physiological disorder can significantly reduce flower quality and yield. Interestingly, a longer pedicel length in the 50 mg L\(^{-1}\) GA\(_3\) treatment was coupled with a higher vase life (less bent neck). This finding supports a previous study showing that GA\(_3\) application can strengthen the stem cell wall by stimulating cell wall component production (Chen et al., 2020). Considering the response of gerbera plants to foliar GA\(_3\) application, which resulted in consistently higher or similar flower quality compared to the control, we believe that a moderate foliar GA\(_3\) application rate (50 mg L\(^{-1}\)) holds promise for improving the gerbera cut flower industry.

Table 2. Flower quality (pedicel length and diameter, number of days to flowering and flower diameter, number per plant and vase life) of gerbera flowers (red ‘Beaudine’; yellow ‘Palm Beach’) grown in the greenhouse under different gibberellic acid application rates and application timings (transplanting and flower induction stages).

| GA\(_3\) rate \(^{(R)}\) mg L\(^{-1}\) | GA\(_3\) application timing (T) | Cultivar (CV) | Pedicel length (cm) | Pedicel diameter (cm) | No. of days to flowering | Flower diameter (cm) | Flower (no. plant\(^{-1}\)) | Unmarketable flowers (no. plant\(^{-1}\)) | Vase life (day) |
|-----------------------------------|---------------------------------|--------------|---------------------|----------------------|--------------------------|----------------------|-----------------------------|-------------------------------|---------------|
| Control (0)                       |                                 |              | 45.1 b              | 6.33                 | 76.2 a                   | 9.80 a               | 9.25                        | 0.06                          | 10.4 b         |
| 10                                |                                 |              | 46.7 b              | 6.53                 | 73.4 ab                  | 8.62 b               | 8.00                        | 0.38                          | 11.4 ab        |
| 50                                |                                 |              | 55.0 a              | 6.37                 | 71.5 b                   | 9.79 a               | 9.38                        | 0.19                          | 11.7 a         |
| 200                               |                                 |              | 56.1 a              | 6.36                 | 71.6 b                   | 10.01 a              | 8.64                        | 0.44                          | 11.1 ab        |
| Transplant                        |                                 |              | 55.8 a              | 6.44                 | 73.0                     | 9.96 a               | 8.00                        | 0.38                          | 11.4           |
| Flowering                         |                                 |              | 49.4 b              | 6.40                 | 71.3                     | 8.98 b               | 9.34                        | 0.29                          | 11.3           |
| Beaudine                          |                                 |              | 48.8                | 6.56 a               | 70.5 b                   | 9.78                 | 7.94 b                      | 0.22                          | 12.6 a         |
| Palm Beach                        |                                 |              | 52.7                | 6.23 b               | 75.8 a                   | 9.33                 | 9.69 a                      | 0.31                          | 9.60 b         |
| P-value                           |                                 |              | R                   | 0.0019               | 0.8234                   | 0.0418               | 0.0365                      | 0.4857                        | 0.3222         |
|                                   |                                 |              | T                   | 0.0223               | 0.8289                   | 0.3314               | 0.0227                      | 0.101                         | 0.649          |
|                                   |                                 |              | R×T                 | 0.1068               | 0.2604                   | 0.4506               | 0.0007                      | 0.1327                        | 0.3766         |
|                                   |                                 |              | CV                  | 0.1013               | 0.0498                   | 0.0006               | 0.2207                      | 0.0154                        | 0.5547         |
|                                   |                                 |              | R×CV                | 0.8566               | 0.3422                   | 0.9527               | 0.9293                      | 0.3874                        | 0.2242         |
|                                   |                                 |              | T×CV                | 0.7516               | 0.3461                   | 0.6166               | 0.752                        | 0.6874                        | 0.3642         |
|                                   |                                 |              | R×T×CV              | 0.0318               | 0.994                    | 0.4294               | 0.0292                      | 0.5887                        | 0.0868         |

Values in columns followed by different letters indicate significant differences between treatments according to Tukey’s HSD test (P≤0.05).

Figure 4. Pedicel length and flower diameter of gerbera flowers (red ‘Beaudine’; yellow ‘Palm Beach’) grown in the greenhouse under different gibberellic acid (GA3) application rates and application times (transplanting and flower induction stages). Different letters above bars indicate significant differences between treatments according to Tukey’s HSD test (P≤0.05).
The number of GA₃ applications per cycle for most nonwoody crops ranges from 2 to 3 times, with 10-15-day intervals between sprays during early growth stages (Leskovar & Othman, 2016, 2018). Three applications of GA₃ (150 mg L⁻¹ applied at days 15, 30 and 45 after transplanting) per cycle on gerbera seedlings significantly increased the number of leaves per plant, chlorophyll content, number of flowers per plant, peduncle length and diameter and flower head diameter compared to the control (0, GA₃) with one and two applications (Mehraj et al., 2013). In this study, two foliar GA₃ sprays per cycle were tested: (1) at the seedling stage (the two GA₃ applications were at days 20 and 30 after transplanting), and (2) at flower initiation (the two GA₃ applications were at days 55 and 65 after transplanting). Although the effect of GA₃ was clearly promotive, the statistical analyses for flower quality variables [main effects (GA₃, application timing, cultivar) and their interactions (GA₃ × application timing × cultivar)] showed that the application timing results were inconsistent. Considering the recommendation of previous studies that GA₃ should be applied at early stages as well as the inconsistent results of GA₃ application timing in this study, we believe that the proper application of foliar GA₃ to gerbera plants occurs during the early growth stages (seedling stage).

Table 3 shows the ANOVA and mean separation (Tukey’s HSD test) for lily cultivars as affected by GA₃ level. During the experimental period (March to September 2019), GA₃ levels were significantly different for Pn, gs and E. Lily plants treated with 10 mg L⁻¹ GA₃ had the lowest Pn, and the lily plants treated with 200 mg L⁻¹ GA₃ had the lowest gs and E. The chlorophyll content index (SPAD) was similar across GA₃ levels (0, 10, 50, 200 mg L⁻¹). Interestingly, the 50 mg L⁻¹ GA₃ treatment was consistently similar to or higher than the control, while the 10 and 200 mg L⁻¹ treatments showed inconsistent results when compared to the control. However, the physiological response (SPAD, Pn, gs, E) of both ‘Eldivo’ and ‘Fangio’ to GA₃ treatments was similar across the study period.

Lily plants that received 10, 50, or 200 mg L⁻¹ exogenous GA₃ had longer stems than untreated control plants (Table 4). Postharvest treatment of lily stems with combined gibberellins (GA₄+7) or GA₃ at 100 mg L⁻¹ increased vase flower life in both cold-stored stems and noncold-stored stems (Ranwala & Miller, 2002). However, only a high level of GA₃ (200 mg L⁻¹) reduced the number of days to flowering (shorter production cycle) compared to the control, 10 and 50 mg L⁻¹-GA₃ applying photosynthetic efficiency and improve sink strength by redistributing photosynthetically assimilated products from leaves to buds (Iqbal et al., 2011; Verma et al., 2017). RNA-seq and qPCR analyses to investigate the effect of exogenous GA₃ (0, 1, or 10 mM) treatment on global gene expression profiles of radish (Raphanus sativus) revealed that 21 and 8 differentially expressed genes were identified as flowering time- and GA-responsive genes, respectively (Jung et al., 2020). Given that GA₃ (50 mg L⁻¹) application reduced the production cycle by 6.2% compared to the control (71.5 vs. 76.2 days) while maintaining high flower quality, we believe that foliar application of 50 mg L⁻¹ GA₃ is of great interest for the cut flower industry.
treatments (Table 4). Further exploration of the GA$_3$ rate × cultivar revealed a significant interaction for the number of days to flowering, flower diameter and vase life (Table 4 and Figure 5). The GA$_3$ rate × cultivar interaction showed that ‘Fangio’ lily at a 200 mg L$^{-1}$ GA$_3$ rate had a shorter flowering period than with the other treatments. Conversely, the ‘Eldivo’ cultivar at 10 and 50 mg L$^{-1}$ GA$_3$ had a higher flower diameter and vase life than the 0 and 200 mg L$^{-1}$-GA$_3$ cultivars. The 50 mg L$^{-1}$ GA$_3$ (especially for ‘Eldivo’) was the only treatment that had consistently higher (stem length, flower diameter, vase life) or similar (stem diameter, flower number per plant) flower quality compared to the control (Table 4, Figure 4). Overall, GA$_3$ application (specifically, 50 mg L$^{-1}$) positively affected flower quality for both species (gerbera and lily) compared to the control.

Table 3. Chlorophyll content index (SPAD), photosynthesis ($P_n$), stomatal conductance ($g_s$), and transpiration ($E$) of Asiatic lily (yellow ‘Eldivo’ and pink ‘Fangio’) grown in the greenhouse under different gibberellic acid application rates.

| GA$_3$ rate (R) mg L$^{-1}$ | Cultivar (CV) | SPAD | $P_n$ (µmol m$^{-2}$ s$^{-1}$) | $g_s$ (mol m$^{-2}$ s$^{-1}$) | $E$ (mmol m$^{-2}$ s$^{-1}$) |
|---------------------------|--------------|------|-----------------------------|-----------------------------|-----------------------------|
| Control (0)               |              | 22.6 | 15.3 a                      | 0.020 bc                    | 1.21 bc                     |
| 10                        |              | 21.9 | 12.8 b                      | 0.037 a                     | 1.99 a                      |
| 50                        |              | 20.5 | 15.4 a                      | 0.030 ab                    | 1.66 ab                     |
| 200                       |              | 19.2 | 14.7 a                      | 0.018 c                     | 1.08 c                      |

Values in columns followed by different letters indicate significant differences between treatments according to Tukey’s HSD test (P≤0.05).

Table 4. Flower quality (stem length and diameter, number of days to flowering and flower diameter, flower number per plant and vase life) of Asiatic lily (yellow ‘Eldivo’ and pink ‘Fangio’) grown in the greenhouse under different gibberellic acid application rates.

| GA$_3$ rate (R) mg L$^{-1}$ | Cultivar (CV) | Stem length (cm) | Stem diameter (cm) | No. of days to flowering | Flower diameter (cm) | Flower (no./plant) | Vase life (days) |
|---------------------------|--------------|------------------|--------------------|--------------------------|----------------------|-------------------|------------------|
| Control (0)               |              | 93.0 b           | 7.49               | 70.3 a                   | 22.0 c               | 3.75              | 8.13 b           |
| 10                        |              | 112 a            | 7.11               | 70.4 a                   | 23.8 a               | 4.00              | 8.75 ab          |
| 50                        |              | 113 a            | 6.97               | 70.5 a                   | 23.0 b               | 3.75              | 9.13 a           |
| 200                       |              | 109 a            | 7.04               | 66.9 b                   | 21.9 c               | 3.88              | 8.38 ab          |

Values in columns followed by different letters indicate significant differences between treatments according to Tukey’s HSD test (P≤0.05).
Conclusions

The study shows how the performance of gerbera and lily is influenced by GA$_3$ level and timing of application. For gerbera, the 50 mg L$^{-1}$ GA$_3$ treatment increased plant height by 30% (55.3 vs. 42.5 cm), pedicel length by 20% (55 vs. 45.1 cm), and vase life by 12.5% (11.7 vs. 10.4 days) and shortened the number of days to flowering by 7% (71.5 vs. 76.2 days) when compared to the control. In the lily experiment, the lower levels of GA$_3$ (10 and 50 mg L$^{-1}$) had consistently higher or similar flower quality results (stem length and diameter, number of days to flowering, flower diameter and number and vase life). Conversely, the highest levels of application of GA$_3$ (200 mg L$^{-1}$) showed inconsistent results. Overall, the application of 50 mg L$^{-1}$ GA$_3$ to gerbera cultivars and 10 or 50 mg L$^{-1}$ GA$_3$ to the lily plants at the seedling stage can potentially improve flower quality and shorten the number of days to flowering compared to the control. Cut flower growers can exploit these results to manage plant growth and enhance species flower quality and economic profit.

Figure 5. Number of days to flowering, flower diameter and vase life of Asiatic lily (yellow ‘Eldivo’ and pink ‘Fangio’) grown in the greenhouse under different gibberellic acid application rates. Different letters above bars indicate significant differences between treatments according to Tukey’s HSD test (P≤0.05).
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