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RESEARCH PAPER

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 (GA_3) 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 GA_3 (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. GA_3 application at the seedling stage increased pedicel length and flower diameter compared to GA_3 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 GA_3 levels in terms of leaf *gs*, *E* and flower diameter. Compared to 0, 10 and 50 mg L^{-1}-GA_3, 200 mg L^{-1}-GA_3 decreased the number of days to flowering. Overall, the application of 50 mg L^{-1}-GA_3 to gerbera and lily cultivars at the seedling stage can potentially improve flower quality and shorten the number of days to flowering.

Keywords: Chlorophyll, GA_3, 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 GA_3, induce growth and yield (Ayad *et al*., 2018; Celis-Arámburo *et al*., 2011). For example, foliar application of GA_3 (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

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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 humboldtianus*) 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_3) 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 (*Pn*, *gs*, 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

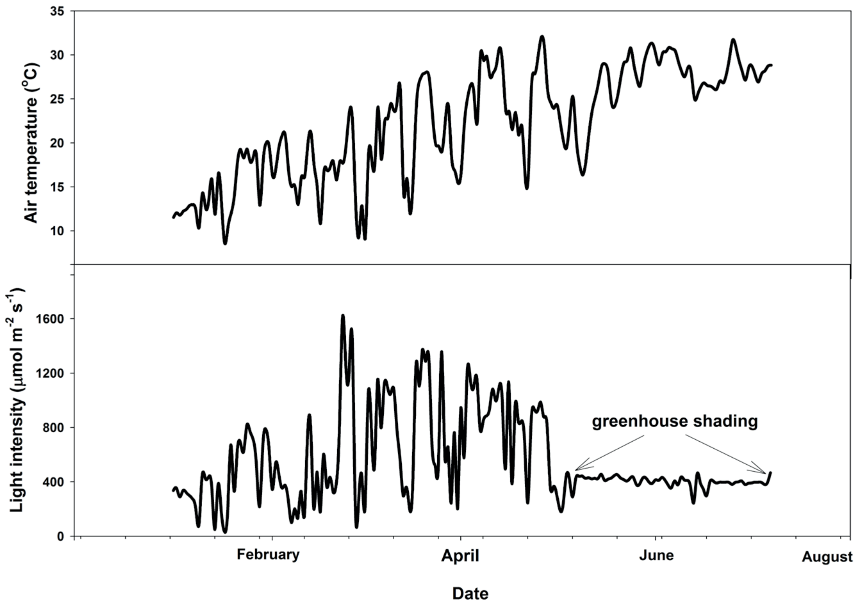

Figure 1. Air temperature and light intensity during the experimental period, March-September 2019.

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 ($P \leq 0.05$) 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-l,6-biphosphatase 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 (*Pn*), stomatal conductance (*gs*), 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	*Pn* (μmol m^{-2} s^{-1})	*gs* (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		56.1	52.0	14.9	0.125	3.77
	Flowering		54.7	52.8	15.4	0.123	3.71
		Beaudine	51.3	50.9 b	15.6 a	0.128	3.86
		Palm Beach	53.0	54.8 a	14.6 b	0.114	3.49
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 *gs* 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 *gs* 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 *gs* and *E*. Overall, the leaf-level physiological response of gerbera cultivars to GA_3 application was not significant or consistent.

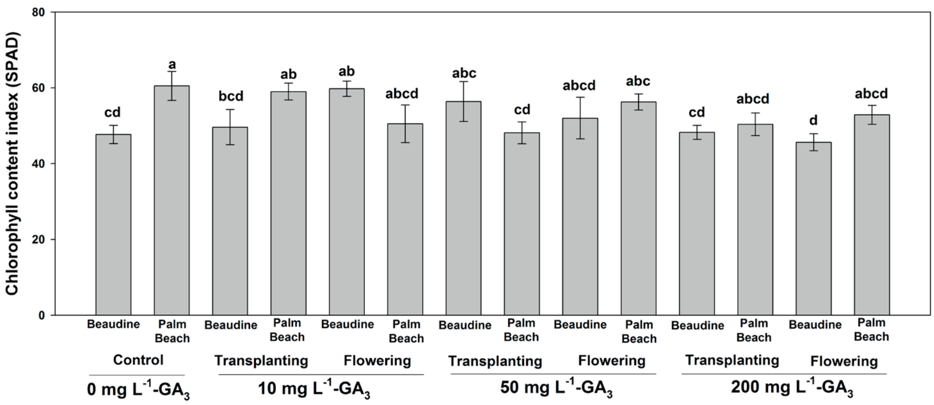

Figure 2. Chlorophyll content index (SPAD) of gerbera flowers (red 'Beaudine'; yellow 'Palm Beach') grown in the greenhouse under different gibberellic acid (GA3) application rates and application times (transplanting and flower induction stages). Different letters above bars indicate significant differences between treatments according to Tukey's HSD test (P≤0.05).

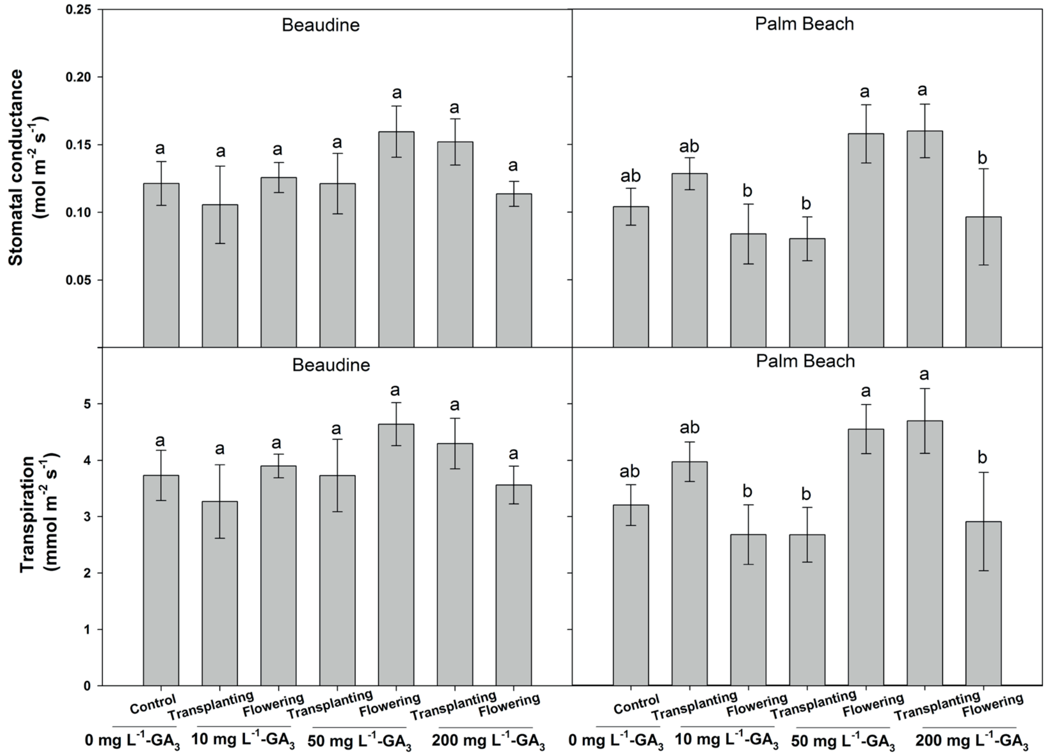

Figure 3. Stomatal conductance and transpiration of gerbera flowers (red 'Beaudine'; yellow 'Palm Beach') grown in the greenhouse under different gibberellic acid (GA_3) application rates and application timings (transplanting and flower induction stages). Different letters above bars indicate significant 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., GA_3), 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 GA_3 (200 mg L^{-1}) can be used to improve flower quality, appearance and, consequently, marketing value for Ceylon Rock Primrose flowers. GA_S 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 GA_3, 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} GA_3 treatment had a higher pedicel length and vase life than the control (Table 4). In addition, the GA_3 rate × application timing × cultivar interaction for pedicel length showed that the control and the 10 mg L^{-1}-GA_3 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 GA_3 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 GA_3 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 [1] (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	0.0485
	T		0.0223	0.8289	0.3314	0.0227	0.101	0.649	0.8346
	R×T		0.1068	0.2604	0.4506	0.0007	0.1327	0.3766	0.383
	CV		0.1013	0.0498	0.0006	0.2207	0.0154	0.5547	<.0001
	R×CV		0.8566	0.3422	0.9527	0.9293	0.3874	0.2242	0.1309
	T×CV		0.7516	0.3461	0.6166	0.752	0.6874	0.3642	0.244
	R×T×CV		0.0318	0.994	0.4294	0.0292	0.5887	0.0868	0.8092

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

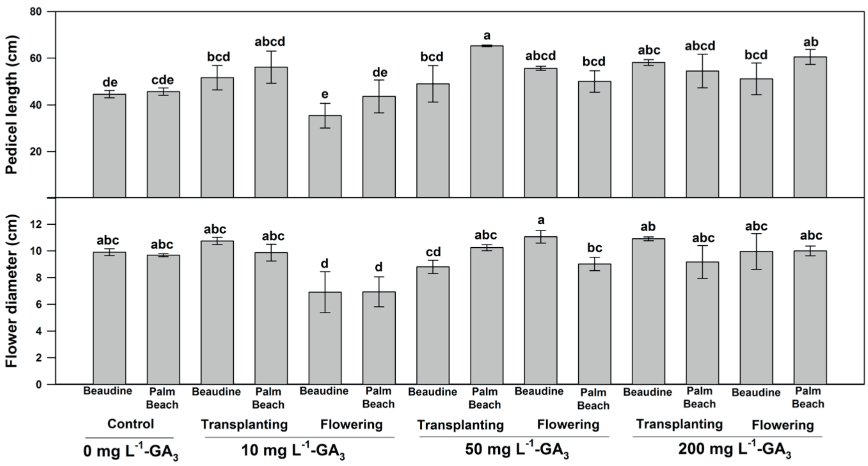

Figure 4. Pedicel length and flower diameter of gerbera flowers (red 'Beaudine'; yellow 'Palm Beach') grown in the greenhouse under different gibberellic acid (GA3) application rates and application times (transplanting and flower induction stages). Different letters above bars indicate significant differences between treatments according to Tukey's HSD test (P≤0.05).

The number of GA_3 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 GA_3 (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, GA_3) with one and two applications (Mehraj *et al*., 2013). In this study, two foliar GA_3 sprays per cycle were tested: (1) at the seedling stage (the two GA_3 applications were at days 20 and 30 after transplanting), and (2) at flower initiation (the two GA_3 applications were at days 55 and 65 after transplanting). Although the effect of GA_3 was clearly promotive, the statistical analyses for flower quality variables [main effects (GA_3, application timing, cultivar) and their interactions (GA_3 × application timing × cultivar)] showed that the application timing results were inconsistent. Considering the recommendation of previous studies that GA_3 should be applied at early stages as well as the inconsistent results of GA_3 application timing in this study, we believe that the proper application of foliar GA_3 to gerbera plants occurs during the early growth stages (seedling stage).

The main objectives of cut flower growers are to increase flower yield and quality and reduce the production cycle. Flower earliness reduces production time and, consequently, input cost. In this study, the number of days to flowering at 50 and 200 mg L^{-1} GA_3 was lower than the number of days to flowering in the control (Table 2). Similarly, Naranja & Balladares (2008) found that foliar application of GA_3 (50 mg L^{-1}) to perennial aster significantly increased plant size, shortened the production cycle by 10 days (48 d vs. 58 d for control) and increased the net profit by 50% compared to untreated plants (Naranja & Balladares, 2008). Gibberellic acids (e.g., GA_3) normally increase source strength by improving 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 GA_3 (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 GA_3 (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} GA_3 is of great interest for the cut flower industry.

Table 3 shows the ANOVA and mean separation (Tukey's HSD test) for lily cultivars as affected by GA_3 level. During the experimental period (March to September 2019), GA_3 levels were significantly different for *Pn*, *gs* and *E*. Lily plants treated with 10 mg L^{-1} GA_3 had the lowest *Pn,* and the lily plants treated with 200 mg L^{-1} GA_3 had the lowest *gs* and *E*. The chlorophyll content index (SPAD) was similar across GA_3 levels (0, 10, 50, 200 mg L^{-1}). Interestingly, the 50 mg L^{-1} GA_3 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 GA_3 treatments was similar across the study period.

Lily plants that received 10, 50, or 200 mg L^{-1} exogenous GA_3 had longer stems than untreated control plants (Table 4). Postharvest treatment of lily stems with combined gibberellins (GA_{4+7}) or GA_3 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 GA_3 (200 mg L^{-1}) reduced the number of days to flowering (shorter production cycle) compared to the control, 10 and 50 mg L^{-1}-GA_3

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 (*Pn*), stomatal conductance (*gs*), 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	*Pn* (μmol m^{-2} s^{-1})	*gs* (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
	Eldivo	21.2	14.6	0.026	1.43
	Fangio	20.9	14.5	0.027	1.53
P-value	R	0.1985	0.0003	0.002	0.0018
	CV	0.8367	0.7426	0.814	0.5277
	R×CV	0.1317	0.7861	0.466	0.3274

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.·$plant^{-1}$)	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
	Eldivo	107.5	7.10	70.6 a	23.8 a	3.81	8.88
	Fangio	106.5	7.21	68.4 b	21.6 b	3.88	8.31
P-value	R	<.0001	0.4152	0.0019	<.0001	0.8845	0.0332
	CV	0.9779	0.6471	0.0044	<.0001	0.8104	0.0922
	R×CV	0.1053	0.2997	0.002	0.0006	0.1499	0.0017

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

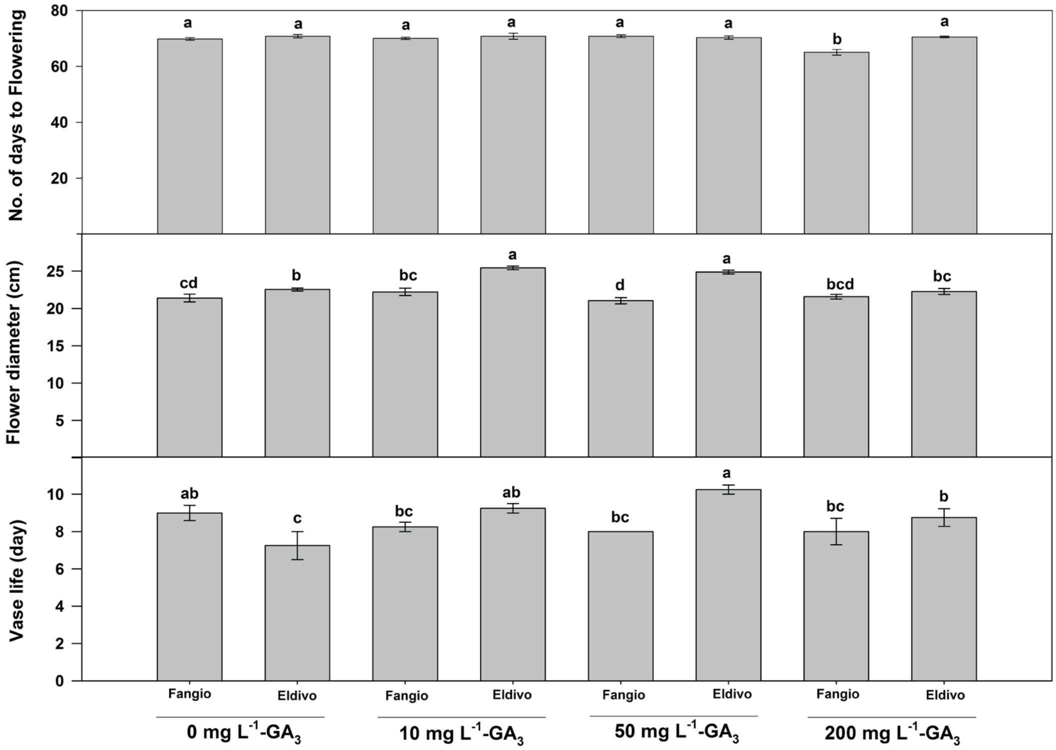

Figure 5. Number of days to flowering, flower diameter and vase life of Asiatic lily (yellow 'Eldivo' and pink 'Fangio') grown in the greenhouse under different gibberellic acid application rates. Different letters above bars indicate significant differences between treatments according to Tukey's HSD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

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 day) 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.

Resumen

Y.A. Othman, M.G. Al-Ajlouni, T.A. A'saf, H.A. Sawalha, y M. Bany Hani. 2021. Influencia del ácido **giberélico en la fisiología y calidad floral de las flores cortadas de gerbera y lirio. Int. J. Agric. Nat. Resour. 21-33.** El objetivo de este estudio era evaluar la influencia de distintos niveles (0, 10, 50, y 200 mg L^{-1}) de ácido giberélico foliar (GA_3) y su fecha de aplicación en el crecimiento, la fisiología (intercambio de clorofila y gas) y la calidad floral de la gerbera (*Gerbera jamesonii* cvs. Beaudine y Palm Beach) y el lirio asiático (*Lilium* × *elegans* cvs. Fangio y Eldivo). La aplicación de GA_3 (50 mg L^{-1}) aumentó (p<0.05) la altura del brote de la gerbera (30 %), la longitud de los pedicelos (20 %), la esperanza de vida en jarrón (12,5 %), y disminuyó el número de días hasta la floración (7 %) en contraste con el control. La aplicación de GA_3 durante la fase de siembra aumentó la longitud de los pedicelos y el diámetro de las flores en comparación con el tratamiento de GA_3 durante la fase de inicio de la floración. Sin embargo, el índice de contenido de clorofila, la fotosíntesis (*Pn*), la conductancia estomática (*gs*) y la transpiración (*E*) fueron similares durante todo el periodo del estudio. En cuanto al lirio asiático, 10 y 50 mg L^{-1} fueron los mejores niveles de GA_3 en términos de crecimiento de hoja, *E* y diámetro de flor. 200 mg L^{-1}-GA_3 disminuyeron el número de días hasta la floración en comparación con 0, 10 y 50 mg L^{-1}-GA_3. En general, la aplicación de 50 mg L^{-1}-GA_3 a los planteles de gerberas y lirios durante la fase de siembra puede mejorar la calidad de las flores y reducir el número de días hasta la floración.

Palabras clave: Clorofila, esperanza de vida en jarrón, flores cortadas, fotosíntesis, GA_3, hormona.

References

Al-Ajlouni, M., Ayad, J., & Othman Y.)2017a). Increasing nutrient levels promote growth and flower quality in lilies grown under soilless culture. *Horticulture Science* 44(4):171–177. doi: 10.17221/166/2016-HORTSCI.

Al-Ajlouni, M., Ayad, J., & Othman, Y. (2017b). Particle size of volcanic tuff improves shoot growth and flower quality of asiatic hybrid lily using soilless culture. *HortTechnology* 27:223–227. doi: 10.21273/horttech03585-16.

Arteca, R.N. (1996). Plant growth substances: principles and applications. First edition. Springer Nature, Switzerland.

Ayad, J., Othman, Y., & Al Antary, T. (2019). Irrigation water salinity and potassium enrichment influenced growth and flower quality of Asiatic lily. *Fresenius Environmental Bulletin* 28(11A):8900–8905.

Burchi, G., Prisa, D., Ballarin, A., & Menesatti, P. (2010). Improvement of flower color by means of leaf treatments in lily. *Scientia Horticulturae* 125:456–460. doi: 10.1016/j.scienta.2010.04.028.

Celis-Arámburo, T., Carrillo-Pech, M., Castro-Concha, L., Miranda-Ham, M., Martínez-Estévez, M. & Echevarría-Machado, I. (2011). Exogenous nitrate induces root branching and inhibits primary root growth in *Capsicum chinense* Jacq. *Plant Physiology and Biochemisty* 49:1456–1464. doi: 10.1016/j.plaphy.2011.09.003.

Chen, R., Yegeng, F., Haifeng, Y., Huiwen, Z., Zhongfeng, Z., Mengling, W., Xing, H., Prakash, L., Yangrui, L., Lihang, Q., & Jianming, W. (2020). Enhanced Activity of genes associated with photosynthesis, phytohormone metabolism and cell wall synthesis is involved in gibberellin-mediated sugarcane internode growth. *Frontiers in Genetics* 11:1142. Retrieved from https://www.frontiersin.org/article/10.3389/fgene.2020.570094

Danaee, E., Mostofi, Y., & Moradi, P. (2011). Effect of GA3 and BA on Postharvest Quality and

Vase Life of Gerbera (*Gerbera jamesonii*. cv. Good Timing) Cut Flowers. *Horticulture, Environment, and Biotechnology* 52:140–144. doi: 10.1007/s13580-011-1581-7.

Forde, B. (2002). The role of long-distance signaling in plant responses to nitrate and other nutrients. *Journal of Experimental Botany* 53:39–43.

Gupta, R., & Chakrabarty, S. (2013). Gibberellic acid in plant: Still a mystery unresolved. *Plant Signaling and Behavior* 8: e25504. doi: 10.4161/psb.25504.

Iqbal, N., Nazar, R., Khan, M., Masood, A., & Khan, N. (2011). Role of gibberellins in regulation of source-sink relations under optimal and limiting environmental conditions. *Current Science* 100:998–1007.

Jiang, X., Li, H., Wang, T., Peng, C., Wang, H., Wu, H., & Wang, X. (2012). Gibberellin indirectly promotes chloroplast biogenesis as a means to maintain the chloroplast population of expanded cells. *The Plant Journal* 72:768–780. doi: 10.1111/j.1365-313X.2012.05118.x.

Jiao, J., Wang, X., & Tsujita, M. (1991). Antagonistic effects of uniconazole and GA_{4+7} on shoot elongation and flower development in ‘Nellie White’ Easter lily. *Scientia Horticulturae* 46:323–331. doi: 10.1016/0304-4238(91)90055-4.

Jung, H., Jo, S.H., Jung, W.Y., Park, H.J., Lee, A., Moon, J.S., Seong, S.Y., Kim, J.-K., Kim, Y.-S., & Cho, H.S. (2020). Gibberellin promotes bolting and flowering via the floral integrators *RsFT* and *RsSOC1-1* under marginal vernalization in radish. *Plants* 9:594. doi: 10.3390/plants9050594.

Kim, K.J., & Kim, K.S. (2005). Changes of endogenous growth substances during bulb maturation after flowering in Lilium oriental hybrid ‘Casa Blanca’. *Acta Horticulturae* 673:661–667. doi: 10.17660/ActaHortic.2005.673.91.

Kiba, T., Kudo, T., Kojima, M., & Sakakibara, H. (2011). Hormonal control of nitrogen acquisition: roles of auxin, abscisic acid, and cytokinin. *Journal of Experimental Botany* 62:1399–1409. doi: 10.1093/jxb/erq410.

Leskovar, D., & Othman, Y. (2016). Low nitrogen fertigation promotes root development and transplant quality in globe artichoke. *HortScience* 51:567–572. doi: 10.21273/HORTSCI.51.5.567

Leskovar, D., & Othman, Y. (2018). Organic and conventional farming differentially influenced soil respiration, physiology, growth and head quality of artichoke cultivars. *Journal of Soil Science and Plant Nutrition* 18:865–880. doi: 10.4067/S0718-95162018005002502.

López-Bucio, J., Cruz-Ramírez, A., & Herrera-Estrella, L. (2003). The role of nutrient availability in regulation root architecture. *Current Opinion in Plant Biology* 6:280–287. doi: 10.1016/S1369-5266(03)00035-9.

Mehraj, H., Taufique, T., Ona, A., Roni, M., & Jamal Uddin, A. (2013). Effect of spraying frequency of gibberellic acid on growth and flowering in gerbera. *Journal of Experimental Biosciences* 4(2):7–10.

Naranja, L., & Balladares, M. (2008). Flowering induction of Aster ericoides (L.) using gibberellic acid. *Philippine Agricultural Scientist* 91:338–342.

Othman, Y., Van Leeuwen, D., Heerema, R., & St. Hilaire, R., (2014). Midday stem water potential values needed to maintain photosynthesis and gas exchange established for pecans. *Journal of the American Society for Horticultural Science* 139:537–546. doi: 10.21273/JASHS.139.5.537.

Othman, Y., Steele, C., Van Leeuwen, D., & St. Hilaire, R. (2015). Hyperspectral surface reflectance data used to detect moisture status of pecan orchards during flood irrigation. *Journal of the American Society for Horticultural Science* 140(5):449–458. doi: 10.21273/JASHS.140.5.449.

Pérez-Jiménez, M., Pazos-Navarro, M., López-Marín, J., Gálvez, A., Varó, P., & M-del Amor, F. (2015). Foliar application of plant growth regulators changes the nutrient composition of sweet pepper (*Capsicum annuum* L.). *Scientia Horticulturae* 194:88–193. doi: 10.1016/j.scienta.2015.08.002.

Ranwala, A., & Miller, W. (2002). Effects of gibberellin treatments on flower and leaf quality of cut hybrid lilies. *Acta Horticulturae* 570:205–210. doi: 10.17660/ActaHortic.2002.570.24.

Sumanasiri, H., Krishnarajah, S., & Eeswara, J. (2013). Effect of gibberellic acid on growth and flowering of *Henckelia humboldtianus* Gardner (Ceylon Rock Primrose). *Scientia Horticulturae* 159:29–32. doi: 10.1016/j.scienta.2013.04.021.

Tadros, M., Al-Mefleh, N., Othman, Y., & Al-Assaf, A. (2021). Water harvesting techniques for improving soil water content, and morpho-physiology of pistachio trees under rainfed conditions. *Agriculture Water Management* 243:106464. doi: 10.1016/j.agwat.2020.106464.

Tiwari, A., Offringa, R., & Heuvelink, E. (2012). Auxin-induced fruit set in *Capsicum annuum* L. requires downstream gibberellin biosynthesis. *Journal of Plant Growth Regulation* 31:570–578.

Verma, I., Roopendra, K., & Sharma, A. (2017). Expression analysis of genes associated with sucrose accumulation in sugarcane under normal and GA_3-induced source–sink perturbed conditions. *Acta Physiologiae Plantarum*. 39(6):133. doi: 10.1007/s11738-017-2433-6.

Vieira, M., Citadini, V., Lima, G., de Souza, A., & Alves, L. (2010). Use of gibberellin in floriculture. *African Journal of Biotechnology* 9:9118–9121.

Wen, Y., Su, S., Ma, L., & Wang, X. (2018). Effects of gibberellic acid on photosynthesis and endogenous hormones of *Camellia oleifera* Abel. in 1st and 6th leaves. *Journal of Forest Research* 23:309–317. doi: 10.1080/13416979.2018.1512394.

Woodson, W. (1991). *Gene Expression and Flower Senescence*. In: Genetics and Breeding of Ornamentals Species. Kluwer Academic Publishers: 317–381.