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Effect of LED Lighting and Gibberellic Acid Supplementation on Potted Ornamentals

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Abstract: Use of light emitting diode (LED) technology is beginning to replace traditional lighting in greenhouses. This research focused on the effects of LED lighting and gibberellic acid supplementation on growth and flowering of *Dahlia* spp. 'Karma Serena', *Liatris spicata* 'Kobold', and *Lilium asiatic* 'Yellow Cocotte'. Light treatments, used to extend photoperiod, included LED flowering lamps and halogen lamps that emitted a combination of red + far-red + white, red + white, and broad spectrum from late fall to early spring. Gibberellic acid treatments ranged from 40 to 340 mg L^{-1} for Asiatic lily 'Yellow Cocotte', 50 to 250 for gayfeather 'Kobold', and 50 to 150 for dahlia 'Karma Serena'. Results varied within species in response to light and gibberellic acid. A significant interaction of light with gibberellic acid influenced mean flower number and flowering percentage for dahlia 'Karma Serena', while flowering percentage and flower diameter were influenced for Asiatic lily 'Yellow Cocotte'. Effect of light was most significant on growth and flowering measurements, especially for gayfeather 'Kobold' and dahlia 'Karma Serena'. For gayfeather 'Kobold', flowering occurred two weeks earlier under sole LED lighting than under other light treatments and no supplemental light. Although flowering occurred the earliest for dahlia 'Karma Serena' under no supplemental light, plants under light treatments had greater height, width, and shoot weight. Significant effects of gibberellic acid on growth and flowering measurements for dahlia 'Karma Serena' and Asiatic lily 'Yellow Cocotte' were observed for height, width, and flower number.

Keywords: light emitting diodes; GA_3; extended photoperiod; greenhouse

1. Introduction

Light is the single most important variable with respect to plant growth and development and is often the most limiting factor in greenhouse production [1]. Therefore, using artificial lighting (AL) or grow lights (GL) in commercial greenhouses is beneficial for plants and growers. Altering photoperiod and increasing light levels are reasons for using these lights. The different lighting sources that growers can use include incandescent (INC) lamps, fluorescent lamps (FL), and high intensity discharge (HID) lamps. Light emitting diodes (LED) are fourth generation lighting sources and are the emerging technology in horticulture [2]. Before choosing a lighting device, several factors, such as efficiency, total energy emissions, life expectancy, and costs need to be considered. In addition, it is important to know the three most important light factors that affect plant growth, which are light quality, light intensity, and light duration [1]. LEDs have proven to be advantageous in all these factors when compared to traditional lighting sources [3].

Energy inputs range from 10% to 30% of total production costs for the greenhouse industry [4]. Thus, any new lighting technology that significantly reduces consumption of electricity for crop lighting, while maintaining or improving crop value is of great interest to growers. Light sources, such as fluorescent, metal halide, high pressure sodium, and incandescent lamps are generally used

for plant growth under greenhouse conditions and have been around for half a century. However, these light sources have disadvantages, such as less suitable wavelength for plant growth and limited lifetime of operation. In addition, they require more electricity and produce heat that may injure plant leaves [5].

In the 1990s, light-emitting diodes (LEDs) were investigated for the first time for plant growth and were found to be efficient alternatives to traditional lamps used in lighting systems [6]. Compared with conventional lamps, LEDs are smaller in size and weight, have a long lifetime, low heat emissions, wavelength specificity, and much lower energy consumption [7]. In addition to changes in plant productivity, increased suppression of pathogens has been noted in tomato *(Solanum lycopersicum* L.) and cucumber (*Cucumis sativis* L.) [8]. Physiological and morphological effects of LEDs have been studied in several species, including potato (*Solanum tuberosum* L.), wheat (*Triticum aestivum* L.), lily (*Lilium candidum* L.), lettuce (*Lactuca sativa* L.), spinach (*Spinacia oleracea* L.), strawberry (*Fragaria* × *ananassa* Duchesne), marigold (*Tagetes erecta* L.), chrysanthemum (*Chrysanthemum indicum* L.), and salvia (*Salvia divinorum* Epling and Játiva) using various LED products [9].

Light-emitting diodes have the potential to shorten the crop time, reduce costs, and add new plants for specialty cut flower production during the winter [7]. This light source may also induce greater flowering for winter crops; however, research is limited to propagation, vegetables, and seedling production. Commercial LED fixtures for photoperiodic lighting have been recently developed for flowering applications and are alternatives to INC lamps. Craig and Runkle [10] quantified how red (R) to far-red (FR) ratio of photoperiodic lighting from LEDs influenced flowering and extended the growth of short-day plants. Kohyama [11] investigated the efficacy of commercial LED products developed for flowering applications on long-day plants. Meng and Runkle [12] coordinated grower trials to investigate the efficacy of R + white (W) + FR LEDs to regulate flowering of daylength-sensitive ornamental crops. For some plants, flowering is promoted with a combination of R and FR light [13,14].

Gibberellic acid (GA_3) is a hormone found in plants, which is produced in low amounts. Synthetic GA_3 is commonly used in commercial agriculture. This hormone is very influential and can control plant development, promote growth, and elongate cells. Gibberellic acid can also promote petal growth and enhance other flowering characteristics [15,16]. In certain plant species, GA_3 acts as a mobile signal transmitter for photoperiodic flowering stimulation [17]. For flower induction, soaking bulbs, rhizomes, corms, or spraying the foliage with a GA_3 solution are common applications [18–20]. There are limited but statistically valid interactions between light and GA_3. Both factors are known to have synergistic effects, but mainly on germination of seedlings [21,22]. In certain species, growth and flower initiation are affected by light and GA_3 application [23,24]. More current research needs to be conducted to assess the interaction of light and GA_3 further. Therefore, objectives of this study were to evaluate how gibberellic acid and different combinations of red and far-red light together from LED flowering lamps and halogen lamps, would influence growth and flowering of *Lilium* L., *Dahlia* Cav., and *Liatris* Gaertn. ex Schreb. species.

2. Materials and Methods

2.1. Plant Material and Culture

On 15 September 2015, bulbs of *Lilium asiatic* L. 'Yellow Cocotte' were graded at 16 to 19 cm. Cuttings of *Dahlia* spp. 'Karma Serena', which are short-day plants, arrived 14 October 2015. *Liatris spicata* (L.) Willd. 'Kobold' corms, which are long-day plants, arrived 12 November 2015 and were graded at 8 to 10 cm. Plant materials were obtained from a broker (Gloeckner and Company Incorporated, Harrison, NY, USA). Before transplanting, dahlia 'Karma Serena' cuttings were placed on a mist bench and Asiatic lily 'Yellow Cocotte' were placed in a cooler at 4 °C upon arrival for one month. Gayfeather 'Kobold' corms were immediately treated with GA_3 (Plant Hormones LLC, Auburn, WA, USA). All bulbs and corms were soaked in an aqueous solution of GA_3 for 30 min before being potted. Dahlia leaves were sprayed to glisten once with different rates of GA_3 solution after

potting. Tween-20 (Sigma-Aldrich, St. Louis, MO, USA) was also added in the GA_3 solution as a surfactant at a concentration of 0.01%. The GA_3 treatment dates were 24 October 2015, 31 October 2015, and 13 November 2015 for 'Yellow Cocotte ', 'Karma Serena', and 'Kobold', respectively. Dahlia 'Karma Serena', Asiatic lily 'Yellow Cocotte', and liatris 'Kobold' were potted in standard 15 cm pots filled with Metro-Mix 360 media (Sun Gro Horticulture, Bellevue, WA, USA) and were placed in the greenhouses on 16 October 2015, 24 October 2015, and 12 November 2015, respectively.

2.2. Experimental Arrangement

The experiment was conducted at four research greenhouses of the Department of Horticulture and L.A. in Stillwater, OK. For each greenhouse, temperatures were set at 23 °C during the day and 18 °C during the night with a photosynthetic photon flux density (PPFD) between 600 to 1200 μmol m^2 s^{-1} and daily light integral of 10–15 mol m^2 d. One light treatment was established in each greenhouse. Light emitting diodes (Philips Green Power Flowering lamps, Amsterdam, The Netherlands) and standard halogen bulbs, which are broad spectrum across the photosynthetically active radiation region, were installed at 0.914 m above the bench area and 0.914 m apart. In the first light treatment, there were 19 14-watt LED R + W + FR flowering lamps (Phillips Lighting, Somerset, NJ, USA) with a spectrum from 420 to 780 nm and peaks at 660 (35%) and 740 (46%). The second light treatment had 11 15-watt LED R + W flowering lamps (Phillips Lighting, Somerset, NJ) with a spectrum from 420 to 720 nm and a peak at 660 (78%) and 12 40-watt halogen bulbs (Osram Sylvania, Wilmington, MA, USA) with a spectrum from 400 to 1200 nm with peaks at 600, 760, and 850 nm with lamps and bulbs installed alternatively. The third light treatment included 23 of the above mentioned 40-watt halogen bulbs, and the fourth treatment did not have lights (control). Plant species and GA_3 rates were randomized within light treatments. Plants were supplemented with seven hours of light after sunset. Before daylight savings time (8 November 2015), lighting was delivered from 1900 to 0200 HR. After daylight savings time, lighting was delivered between 1700 to 2400 HR using timers. A quantum sensor (Spectrum Technologies, Inc., Aurora, IL, USA) measured photosynthetic photon flux density (PPFD) of the LED lamps and halogen bulbs. In each greenhouse where the light was supplemented, measurements were randomly recorded across the bench area and were taken at pot level. The mean photon outputs were 10, 20, and 2 μmol m^{-2} s for LED emitting R + W + FR, LED emitting R + W, and halogen, respectively.

Gibberellic acid rates for gayfeather 'Kobold' were 50, 170, and 250 mg L^{-1} with 12 pots per rate per light treatment. Asiatic lily 'Yellow Cocotte' had rates of 40, 140, and 340 mg L^{-1} with 12 pots per rate per light source. Dahlia 'Karma Serena' rates were 50, 100, and 150 mg L^{-1} with 10 pots per rate per light source. All plants included a controlled rate in which water was used. Plants were watered with drip irrigation as needed. On 23 November 2015, a slow release fertilizer 16-9-12 (3–4 month, Osmocote® Plus, The Scotts Co., Marysville, OH, USA) at a rate of 10 g was added at time of potting and 200 mg L^{-1} 20-10-20 Peat-lite (Jacks, Allentown, PA, USA) water soluble fertilizer was supplemented after three weeks.

2.3. Harvesting and Measurements

Data collected from plants included the date of first flower (anthesis), which was only recorded when petals were fully opened. Flower diameter was recorded on 15 November 2015 for dahlia 'Karma Serena' and 22 December 2015 for Asiatic lily 'Yellow Cocotte' using a digital caliper (Tresna Instrument., LTD, Guilin, China). Flowering percent (flowering or not per pot), Number of flowers, plant height (from media surface to tallest flower or bud), and width (average of two perpendicular measurements) were recorded on 18 January 2016 for dahlia 'Karma Serena', 22 Feburary 2016 for Asiatic lily 'Yellow Cocotte', and 27 Feburary 2016 for gayfeather 'Kobold'. Shoot dry weight was recorded on 1 Feburary 2016 for dahlia 'Karma Serena', 29 Feburary 2016 for Asiatic lily 'Yellow Cocotte', and 7 March 2016 for gayfeather 'Kobold' by cutting the stems at the media level, and drying for 3 d at 54.4 °C.

2.4. Statistical Analysis

Pots were arranged in a completely randomized design with plant species, GA_3 and light treatments as the specified factors. Data were analyzed with SAS version 9.4 software (SAS Institute, Cary, NC, USA). An analysis of variance methods (PROC MIXED) was used with a two-factor factorial arrangement with light and GA_3 as the factors of interest. For percentage response variables, arcsine square root transformations were used to help normalize the data. Because the levels of the factors changed, separate analyses were conducted for each plant species. When interactions of light with GA_3 were significant, simple effects were reported. Mean separations were determined using protected Fisher-type comparisons (a DIFF option in an LSMEANS statement and a SLICE option when appropriate) and with 0.05, 0.01, 0.001, and 0.0001 levels of significance.

3. Results

3.1. Liatris spicata 'Kobold'

A main effect of light was found on all growth measurements, as well as on a number of terminal spikes and days to anthesis (Table 1). Plants under LEDs flowered the earliest, but were not different than halogen or LED + halogen (Table 2). The average number of spikes was greatest with natural light, which was not different than halogen. Plant height and width was greatest under LED and LED + halogen. Shoot dry weight was greatest with halogen lighting. Gibberellic acid rates had a significant effect on plant width, shoot dry weight, and mean spike number (Table 1). For width, plants receiving 0 mg L^{-1} GA_3 were greatest, but were not different from those treated at 50 and 170 mg L^{-1} GA_3 (Table 3). Shoot weight was greatest for 0 mg L^{-1} GA_3, but was not different from 50 and 250 mg L^{-1} GA_3. The average number of spikes was greatest at 250 mg L^{-1} GA_3, but was not different than 0 or 170 mg L^{-1} GA_3.

Table 1. Analysis of variance for growth and flowering measurements of *Liatris spicata* 'Kobold', *Dahlia* spp. 'Karma Serena', and *Lilium asiatica* 'Yellow Cocotte' grown with LED and halogen lights along with multiple rates of gibberellic acid.

Cultivar	Source	Height (cm)	Width (cm)	Shoot Dry Weight (g)	Flowers/Spikes Number [z]	Flower Diameter	Days to Anthesis	Flowering (%)
'Kobold'	Light	**** [y]	****	****	****	- [x]	****	ns
	GA_3	ns	**	*	*	-	ns	ns
	Light × GA_3	ns	ns	ns	ns	-	ns	ns
'Karma Serena'	Light	****	****	****	****	ns	****	ns
	GA_3	****	ns	ns	**	*	ns	ns
	Light × GA_3	ns	ns	ns	*	ns	ns	*
'Yellow Cocotte'	Light	ns	ns	ns	ns	ns	ns	ns
	GA_3	ns	ns	ns	ns	ns	ns	ns
	Light × GA_3	ns	ns	ns	ns	*	ns	*

[z] Number of flowers for 'Karma Serena' and 'Yellow Cocotte', but the number of spikes for 'Kobold'. [y] NS, *, **, ***, **** indicate non-significant or significant at $p \leq 0.05$, 0.01, 0.001, 0.0001, respectively. [x] Data not taken.

Table 2. Growth and flowering measurements of *Liatris spicata* 'Kobold', *Dahlia* spp. 'Karma Serena', and *Lilium asiatica* 'Yellow Cocotte' affected by light averaged across GA_3.

Light Type	Height (cm)	Width (cm)	Shoot Dry Weight (g)	Flower Measurements [z]	Days to Anthesis	Flowering (%)
			'Kobold'			
Control	47.3b [y]	35.2c	13.9b	3.5a	88a	96a
LED	64.7a	49.4a	17.2b	2.3bc	70b	100a
Halogen	52.1b	40.9b	22.0a	3.1ab	73b	98a
LED + Halogen	65.9a	44.9ab	16.8b	1.8c	77ab	98a
			'Karma Serena'			
Control	58.9b	32.5c	9.1d	7.1a	46c	- [x]
LED	67.1b	43.9b	35.0c	7.1a	61b	-
Halogen	95.8a	46.7b	43.6b	8.5a	74a	-
LED + Halogen	85.9a	56.9a	52.9a	7.9a	80a	-
			'Yellow Cocotte'			
Control	45.5a	15.0a	4.0a	2.4a	54a	-
LED	44.5a	19.6a	3.5a	2.0a	47a	-
Halogen	38.4a	16.3a	4.2a	2.0a	43a	-
LED + Halogen	54.1a	19.8a	4.8a	2.1a	55a	-

[z] Mean number of flower spikes for 'Kobold', flower diameter (cm) for 'Karma Serena', and flower number for 'Yellow Cocotte'. [y] Means (n = 12 for 'Kobold' and 'Yellow Cocotte'; n = 10 for 'Karma Serena') with the same letter within the same column are not statistically significant ($p < 0.05$). [x] Interaction significant for plant measurements.

Table 3. Growth and flowering measurements of *Liatris spicata* 'Kobold', *Dahlia* spp. 'Karma Serena', and *Lilium asiatica* 'Yellow Cocotte' affected by GA_3 averaged across the light.

GA_3 Rate (mg L^{-1})	Height (cm)	Width (cm)	Shoot Dry Weight (g)	Flower Measurements [z]	Days to Anthesis	Flowering (%)
			'Kobold'			
0	59.7a [y]	47.4a	19.8a	2.4ab	77a	98a
50	59.5a	43.2ab	17.6ab	2.3b	76a	94a
170	54.6a	40.6ab	15.2b	2.6ab	78a	100a
250	56.3a	39.3b	17.3ab	3.5a	76a	100a
			'Karma Serena'			
0	65.0b	45.5a	30.5a	8.6a	67a	- [x]
50	81.0a	45.7a	35.8a	7.3ab	62a	-
100	81.3a	45.5a	38.5a	6.8b	64a	-
150	80.3a	43.4a	35.7a	7.8ab	69a	-
			'Yellow Cocotte'			
0	48.5a	19.6a	4.5a	2.1a	- [x]	- [x]
40	47.2a	16.8a	4.4a	2.4a	-	-
140	42.9a	17.3a	3.9a	2.0a	-	-
340	43.4a	17.0a	3.7a	2.0a	-	-

[z] Mean number of flower spikes for 'Kobold', flower diameter (cm) for 'Karma Serena', and flower number for 'Yellow Cocotte'. [y] Means (n = 12 for 'Kobold' and 'Yellow Cocotte'; n = 10 for 'Karma Serena') with the same letter within the same column are not statistically significant ($p < 0.05$). [x] Interaction significant for plant measurements.

3.2. *Dahlia spp.'Karma Serena'*

There was a significant Light × GA_3 interaction for mean flower number and flowering percentage (Table 1). Flower number within the 50 mg L^{-1} GA_3 rate was greatest for plants under halogen, LED + halogen, and no supplemental light (Table 4). Plants treated with 100 mg L^{-1} GA_3 treatment, no supplemental light, LEDs, and halogen had the greatest number of flowers. The flowering percentage within the 50 and 150 mg L^{-1} GA_3 rates was greatest with no supplemental lighting, halogen, and

LED + halogen light. Plants treated with 100 mg L^{-1} GA_3 treatment, flowering was greatest with natural light, LED, and halogen lighting. The light had a significant effect on height, width, shoot dry weight, and days to anthesis (Table 1). Time to flower was longest under halogen and LED + halogen (Table 2). Height was greatest under halogen, which was not different than LED + halogen. Plant width and shoot dry weight were greatest under LED + halogen. Only height and flower diameter were significantly affected by GA_3 (Table 1). All GA_3 rates produced taller plants compared to no supplemental lighting. No supplemental lighting had the greatest number of flowers though 50 and 150 mg L^{-1} GA_3 were not different (Table 3).

Table 4. Mean flower number and flowering percent of *Dahlia* spp. 'Karma Serena' and *Lilium asiatica* 'Yellow Cocotte' affected by the interaction of light with GA_3.

Plant	Characteristic	Source	GA_3 (mg L^{-1})			
			0	50	100	150
'Karma Serena'	Flower number	Control	3.1c [z]	2.4b	2.3b	2.8a
		LED	2.2c	2.9b	3.1ab	3.1a
		Halogen	6.6a	5.4a	4.4a	3.7a
		LED + Halogen	5.1b	4.5a	4.4a	2.3a
	Flowering percent	Control	100a	100a	100a	100a
		LED	100a	89b	100a	80b
		Halogen	100a	100a	100a	100a
		LED + Halogen	100a	100a	80b	100a
'Yellow Cocotte'			0	40	140	340
	Flower diameter	Control	8.9b	9.2b	9.7a	9.7b
		LED	10.4a	9.8b	10.4a	10.1ab
		Halogen	9.8b	9.4b	10.1a	9.5b
		LED + Halogen	10.5a	10.7a	10.0a	10.9a
	Flowering percent	Control	58b	67b	58bc	75ab
		LED	100a	67b	75a	50bc
		Halogen	75ab	75a	33c	33c
		LED + Halogen	58b	75a	67ab	100a

[z] Means (n = 10 for 'Karma Serena'; n = 12 for 'Yellow Cocotte') with the same letter within the same column and within plant characteristic are not statistically significant ($p < 0.05$).

3.3. *Lilium* Asiatic 'Yellow Cocotte'

The interaction of Light × GA_3 was seen on flower diameter and flowering percentage (Table 1). Plants treated with 0 mg L^{-1} GA_3 rate, LED and LED + halogen had the greatest flower diameter (Table 4). Plants treated with 40 mg L^{-1} GA_3 rate had the greatest flower diameter under LED + halogen. Plants treated with 340 mg L^{-1} GA_3 rate, plants under LED and LED + halogen had the greatest flower diameters. The flowering percentage was greatest with halogen within the 0 mg L^{-1} GA_3 rate, but was not different from halogen. Plants treated with 40 mg L^{-1} GA_3 rate, plants with halogen and LED + halogen had the greatest flowering percentage. Plants treated with 140 mg L^{-1} GA_3 rate, plants with LED had the greatest flowering percentage, but were not different from LED + halogen. Plants treated with 340 mg L^{-1} GA_3 rate, plants under LED + halogen had the greatest flowering percentage, but were not different from natural lighting. No significant effects were seen by light or GA_3 as main effects on other growth and flowering measurements of 'Yellow Cocotte'.

4. Discussion

The use of LED, LED + halogen, and sole halogen lamps emitting R and FR light effectively promoted growth and flowering in gayfeather 'Kobold' and dahlia 'Karma Serena'. Red light is the most effective at inhibiting flowering in short-day plants (SDP). This was true for dahlia under LED, halogen, and LED + halogen (Table 2). Craig and Runkle [10] reported that flowering in SDPs, such as chrysanthemum (*Chrysanthemum indicum* L.) and dahlia was delayed under incandescent and LED lights. Inhibition of flowering by R light was also seen in cocklebur (*Xanthium strumarium* L.),

chrysanthemum, and soybean (*Glycine max* L. Merr.) [25–27]. Delaying flowering in SDPs, such as dahlia especially during the winter months is ideal. During this season, the days are shorter, and the nights are longer. Therefore, SDPs will want to spend photosynthates in the production of reproductive organs, which will result in a lack of growth and development of vegetative parts. Extended growth and greater biomass are promoted under R light, and this was seen for liatris and dahlia under LED flowering lamps and halogen lamps (Table 2). Miyashita et al., [28] noted that R light from LEDs increased shoot length of potato (*Solanum tuberosum* L.) plantlets. Height was also greatest under either LED flowering lamps emitting R + W or R + W + FR, as well as incandescent lamps in ageratum (*Ageratum houstonianum* L.), calibrachoa (*Calibrachoa* x *hybrida* Cerv.), dianthus (*Dianthus* L.), and petunia (*Petunia* x *hybrida* Juss.). Height and shoot dry weight were greatest for salvia (*Salvia splendens* Sellow ex J.A. Schultes) and tomato (*Solanum lyopersicum* L.) under LEDs emitting red [29]. Meng and Runkle [12] reported that the stem length of verbena (*Verbena* x *hybrid* L.) increased under incandescent and LED flowering lamps compared to the control. Dry weight and plant width increased in poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) when grown under supplemental LED lighting emitting R and blue [30]. An increase in all these growth parameters is beneficial for cut flowers.

A combination of R + FR is effective for promoting flowering in long-day plants (LDP). This was true for liatris that were under sole LED lighting emitting R + W + FR (Table 2). Meng and Runkle [12] have also reported that photoperiodic lighting with a mixture of R and FR light from LEDs and incandescent lamps was most effective at promoting flowering in LDPs. The flowering of *Gypsophila paniculata* (L.) 'Baby's Breath' and *Eustoma grandiflorum* (Salisb.) 'Lisianthus' was also promoted under a combination of R and FR light [13,14]. The presence of FR in LED lamps shortened the flowering time and increased number of flowers in petunia. Hastening of flowering, while maintaining plant quality, will decrease the costs of labor and inputs, as well as assure an early market season. Neither R nor FR light from the lamps influenced flowering in Asiatic lily 'Yellow Cocotte'. Bieleski et al. [31] also reported that the use of R light as a night-break was not effective for increasing anthesis or flower bud opening in multiple cultivars of Asiatic lilies. It was also noted that flowering in lilies was more influenced by variations in day-length and not night interruption with supplemental lighting.

Gibberellic acid (GA_3) effectively promoted growth and flowering measurements in gayfeather 'Kobold', lily 'Karma Serena', and Asiatic lily 'Yellow Cocotte'. Previous research has noted the presence and influence of GA_3 in growing tissues, shoot apices, leaves, and flowers [32]. Cell division and expansion are stimulated by GA_3, especially in response to light or darkness [33]. Flower initiation, development, sex expression, and number are also regulated by GA_3 [34]. Bulyalert [35] reported that exogenous applications of GA_3 increased width and height, as well as the flowering percentage in liatris. The significant effect of GA_3 on flower diameter and height in three cultivars of dahlia was not analyzed, but an increase in these features was observed and reported [36]. Flower diameter was also increased in Asiatic hybrid cut lily flowers when treated with GA_3 and a standard preservative [37]. The following studies have reported similar results in other cut flowers. Application of GA_3 promoted shoot elongation in different cultivars of chrysanthemums [38,39]. Foliar application of GA_3 increased stem length in a variety of cut flower cultivars that were field-grown [40]. Bultynck and Lambers [41] reported that the addition of exogenous GA_3 promoted leaf elongation and increased shoot biomass in *Aegilops caudata* (L.) and *Aegilops tauschii* (L.). Pobudkiewicz and Nowak [42] found that flowering size of gerbera (*Gerbera jamesonni* Hooker f.) was enhanced when GA_3 was applied at 200 mg L^{-1}. Mean flower number was increased in philodendron (*Philodendron* Schott) 'Black Cardinal' as GA_3 concentrations increased [43]. Dobrowolska and Janicka [44] also reported that application of GA_3 at a concentration of 10 mg dm^{-3} increased flower number in *Impatiens hawkeri* (L.) 'Riviera Pink'.

Interaction of light with GA_3 effectively promoted growth and flowering measurements of dahlia 'Karma Serena' and Asiatic lily 'Yellow Cocotte'. Yamaguchi and Kamiya [45] have concluded that light and GA_3 are highly interactive and are involved in the same pathways that regulate germination and dormancy. Light and GA_3 are likely interacting with similar pathways regulating growth and flowering. A study reported that cell expansion was promoted in the leaves of dwarf bean (*Phaseolus vulgaris* L.)

and stem elongation was increased in garden peas (*Pisum sativa* L.) when exposed to FR light and saturated with GA_3 [46]. In Kentucky bluegrass (*Poa pratensis* L.), shoot elongation was increased when endogenous levels of GA_3 interacted with light [47]. Williams and Morgan [48] noted that the exposure of GA_3 to FR light hastened flowering in sorghum (*Sorghum bicolor* L.). White et al. [49] reported that although potted greenhouse plants *Aquilegia* × *hybrida* (L.) 'Bluebird' and 'Robin' all flowered when treated with 100 mg L^{-1} exogenous GA_3, there was no synergistic effect with the supplemental lights emitting R and FR. An increase in flower number was also observed, but not due to an interaction of light with GA_3. Another study reported that GA_3 should be applied to plants before cold temperature exposure and light treatments should be applied after cold temperature exposure to improve floral development. There could be even more of an effect between light and GA_3 on lily bulbs based on exposure to cold temperatures before or after as Asiatic lily 'Yellow Cocotte' were the only plants exposed to a cold treatment before applications of GA_3 and light treatments. Possibly, the exposure to cold temperatures before GA_3 treatment contributed to the lack of growth and flowering rates.

5. Conclusions

Light emitting diode flowering lamps are equally effective as halogen lamps at regulating growth and flowering. Although the LED flowering lamps and halogen bulbs have similar light intensity, the energy consumption of LEDs was 14 to 15 watts per lamp, whereas halogen bulbs use considerably more watts per bulb. Not only was there an improvement in energy use, but the quality of plants was maintained and improved with the use of LED flowering lamps. Results of this study and that of many others show that GA_3 also plays an important role in flowering stimulation, as well as plant growth. In addition, light and GA_3 have a synergistic relationship with each other regarding plant and flower development of plants. More research needs to be conducted using an array of LED flowering lamps with different spectrums, and in combination with the plant hormone GA_3 to control plant growth and flowering, as affects are species dependent.

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