Cut-flower Carnation Photoluminescence: Potential New Value-added Product

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Abstract. Success of the floral industry lies in strengthening the fresh flower market with value-added products. An experiment was conducted to quantify luminescence of cut-flower white carnations after exposure to two fluorescent products (dye from a yellow highlighter or glow-in-the-dark spray paint). Single stems were placed in bud vases that were filled with 240 mL deionized water and 2 g floral preservative. Highlighter treatments were applied to the vase as either one drop, three drops, or half of the dye reservoir (half stick). Paint treatments were applied at 2-, 4-, or 6-second durations to the flowers. Combination treatments were applied as three drops of highlighter dye plus either 2, 4, or 6 seconds of paint application. Treatments were compared against each other and a nontreated control. There were five repetitions of three stems per treatment arranged in a completely randomized design. Measurements were taken daily on stem fresh weight, flower diameter, quality rating, flower maximum brightness, flower mean brightness, relative stem fresh weight percentage, overall solution absorption rate percentage, and daily solution absorption rate. Stem fresh weight, relative stem fresh weight percentage, flower diameter, and overall solution absorption rate were greatest on day 4. Flower maximum brightness without ultraviolet (UV) light was greatest 2 days after treatment (DAT), but still produced a detectable glow through 8 DAT. Among treatments before UV charge, the 6-second paint duration provided the greatest flower maximum brightness value. The half-stick highlighter treatment had the greatest vase mean brightness. All paint treatments reduced flower quality. For each treated flower, the UV charge increased the brightness values, which ranged from 53% to 206% greater than before the UV charge. White carnations can luminesce with spray applications of glow-in-the-dark spray paint or through the stem absorption method using yellow highlighter dye, with the latter being less detrimental to vase life but requiring a UV light source to glow.

Carnation (*Dianthus caryophyllus* L.) is one of the most important cut flowers, ranking in the top five among cut flowers in the world (Maitra and Roychowdhury, 2013). Although carnations are sold year-round, flowers are in more demand around holidays such as Valentine's Day and Mother's Day

(Nowak and Rudnicki, 1990). Carnation cut-flower production occurs mostly in Africa, Latin America, Middle East Asia, and Asia, which export 99% of total carnation sales in the United States (Nelson, 2012). The two main carnation cut flowers are of the standard type, which have one flower on a stem, and the spray type, which have multiple flowers on a stem. Current cut-flower varieties of carnation have been selected for flower size, petal number, stem length, disease resistance, and postharvest longevity (Satoh et al., 2005).

Most carnation cut-flower studies have focused on improving vase life and postharvest quality vs. marketability (Chang-li et al., 2011; Hamidimoghadam et al., 2014; Heins and Blakely, 1980; Koohkan et al., 2014; Lou et al., 2021; Reid et al., 1980; Satoh et al., 2005). However, improving the marketability of cut flowers such as carnations has practical significance for the development of the cut-

flower industry (Aalifar et al., 2020). One way to improve marketability is to tint flowers using dyes. As long ago as 1882, reports have been published on use of dyes for stem absorption in roses (*Rosa* L.), daffodils (*Narcissus* L.), ox-eye daisies (*Chrysanthemum leucanthemum* L.), dianthus (*Dianthus* L.), and sweet peas (*Lathyrus odoratus* L.) (Nesbit, 1882). Within 10 years, artificially dyed green carnations were fashionable, and were adopted by members of the Green Carnation political party in London (Nelson, 2016). Kraemer (1905) proposed that the use of aniline dyes could serve a practical purpose to meeting the demand for certain colors, if demand was greater than supply, or to create new markets where niche hues may be desired (e.g., funeral flowers). Florists and producers today still use methods such as dip dyeing, spraying, and stem absorption to get novel colors, because flower color is one of the most attractive characteristics of ornamental plants (Hunter, 2012; To and Wang, 2006). Value-added techniques such as coloring white flowers artificially can increase crop values 5 to 10-fold (Mekala et al., 2012).

In addition to changes in hue, horticultural industries may be able to increase crop value by creating photoluminescent plants and flowers. One approach to creating photoluminescence in plants uses genetic modification (Li and Pei, 2006). Specifically, the green fluorescent protein from jellyfish (*Aequorea victoria*) has been widely used as a recombinant protein tag in vivo (Cubitt et al., 1995; Kendall and Badminton, 1998; Sacchetti et al., 2000). However, generation and commercialization of luminescent flowers has been mostly limited to studies related to gene expression, protein localization, protein-protein interactions, plant-bacteria interactions, and cell-to-cell communications, because the opacity to UV light and blue light used to excite green fluorescent protein and to regenerate transgenic tissues is still difficult (Hu and Kerppola, 2003; Mercuri et al., 2002; Pérez-Clemente et al., 2004; Wang et al., 2006; Zhang et al., 2002). As an exception, since 1996, Suntory Flowers Limited (Tokyo, Japan) has released 10 genetically modified carnations are part of the Florigene[®] Moon-carnation series that possess the F3'5'H gene that expresses violet hues (Chandler and Tanaka, 2007).

A more practical approach to creating photoluminescence in horticultural plants involves exogenous application of phosphorescent materials. Phosphorescence, a type of photoluminescence, is when a molecule absorbs a photon of a shorter wavelength, leading one of its electrons to a higher energy level, where it radiates at a longer wavelength over a longer period of time as the electron returns to its original state (Chiatti et al., 2021). Most glow-in-the-dark materials use the phosphors zinc sulfide or the newer strontium aluminate, whereas highlighters use pyranine or fluorescein. Glow-in-the-dark or photoluminescent materials carry phosphors that absorb low-energy light and then re-emit visible light as luminescence or glow (Poelman et al., 2020). The addition of UV light

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excites the phosphors, resulting in ordinary luminescence and persistent luminescence as charge carriers are transferred from the activator to the traps, and those traps are filled gradually, storing excitation energy (Poelman et al., 2020). Low-energy light (red light) can be used to excite some phosphors, but high-energy photons, found in the UV band, are most effective at charging the traps. Properties such as depth, type, number, and capacity can affect luminescence persistence. Khattab et al. (2019) incorporated phosphorescent strontium aluminate into globe artichoke (*Cynara cardunculus* L.) roots by soaking the roots in a nutrient solution with a luminescent chemical to cause the roots to glow. McCarty et al. (2019) applied glow-in-the-dark paint to peace lily (*Spathiphyllum wallisii* Regel) 'Petite' leaves and reported phosphorescence for more than 4 weeks after application. Use of phosphorescent products on cut flowers has not been investigated. Thus, the objective of this study was to evaluate two different products for luminescence and vase life on cut-flower carnations as a value-added product.

Material and Methods

Plant material. Standard carnation (*Dianthus caryophyllus* L.) cut flowers were received from Bear Creek Farms (Stillwater, OK) on 2 June 2021 from a cooler set at 3.3 °C. Stems were cut to 40 cm at a 45° angle with leaves removed from the lower 10 cm of the stem. The carnations were then placed into fluted glass bud vases, one flower per vase, filled with 240 mL deionized water and 2 g floral preservative (Syndicate Sales Inc., Kokoma, IN) from 2 June through 13 June 2021. Vases were kept in a climate-controlled room at the Greenhouse Learning Center at Oklahoma State University at a consistent temperature of 21.1 °C and under fluorescent lighting.

Experimental setting and treatments. On 2 June 2021, nine treatments plus a nontreated control were assigned randomly to experimental units. Treatments used either a water-soluble fluorescent dye obtained from a standard 7.3-oz yellow highlighter (Staples the Office Store, Farmingham, MA), a glow-in-the-dark aerosol spray paint (Rust-Oleum Corporation, Vernon

Hills, IL), or a combination of the two. Dye treatments were applied directly to the vase solution at a rate of 1 drop, 3 drops, or half of the dye reservoir (hereafter referred to as a half stick). Paint was applied to the flowers for either 2, 4, or 6 s. Last, three combination treatments were applied using 3 drops of highlighter dye plus 2, 4, or 6 s of paint. Each treatment was applied to a set of three stems and was replicated five times, resulting in 15 vases per treatment. The vases were arranged in a completely randomized design.

Data collection. Measurements were taken daily on stem fresh weight (combined weights of stem and flower), flower diameter (average of two perpendicular measurements with a ruler), and visual deterioration. Visual deterioration was evaluated on a 1- to 4-point scale (1 point, no browning; 2 points, browning around the edges; 3 points, some browning throughout flower; and 4 points, complete browning and a shriveled flower). For quantification of brightness, images were taken of the flowers in darkness using the camera on a smartphone (iPhone XS Maximum; Apple, Cupertino, CA) (Fig. 1). Images were collected before black-light exposure (flower mean and maximum brightness without UV) and again with a 230-nm black light (Sunlite Industrial Corp., El Monte, CA), and are reported as flower mean and maximum brightness with UV. Photos were analyzed for brightness using ImageJ (version 1.53j; NIH, Bethesda, MD) (Schneider et al., 2012) to measure the mean, maximum, and minimum brightness between 0 and 255 of the outlined luminescent flower (Labno, n.d.). A photo was also taken of a commercially available glow-in-the-dark star (MLM, Amazon, Seattle, WA) to use as a reference point for mean and maximum brightness values. Brightness duration (glow after charge without recharge) was evaluated on three additional stems per treatment after the initial experiment to determine how long brightness would last. The experiment was concluded on 13 June 2021 after all flowers had a deterioration rating of 4 points. When concluded, flowers were dried for 3 d at 60 °C to acquire stem dry weight.

Calculations. The relative fresh weight percentage [(current stem fresh weight/stem

Fig. 1. Carnation in complete darkness with spray paint treatment applied.

fresh weight on day 1) × 100] (He et al., 2006), the water content on day 9 [(stem fresh weight – stem dry weight)/stem fresh weight] (Sedaghatthoor et al., 2020), the flower diameter change rate [(current flower diameter/flower diameter on day 1) × 100] (Lou et al., 2021), overall solution absorption rate {[(current stem fresh weight – stem fresh weight on day 1)/stem fresh weight on day 1] × 100} (Sedaghatthoor et al., 2020), and the daily solution absorption rate [(previous day stem fresh weight – current day stem fresh weight)/stem fresh weight on day 1] were calculated.

Statistical analysis. Statistical analysis was performed using SAS/STAT software (version 9.4; SAS Institute, Cary, NC). Tests of significance were reported at the 0.05, 0.01, and 0.001 levels. The data were analyzed using generalized linear mixed-models methods. Tukey's multiple comparison methods were used to separate the means.

Results

Flower mean brightness without UV, flower mean brightness with UV, and quality rating each showed a significant day ×

Table 1. Analysis of variance for stem and flower characteristics, water relations, and brightness after application of glow-in-the-dark spray paint and yellow highlighter of cut-flower carnations at the Greenhouse Learning Center Head House (Stillwater, OK) in 2021.

	Day	Treatment	Day × treatment
		P value	
Stem dry weight	—	0.0350	—
Stem fresh weight	<0.0001	0.1314	0.4287
Flower diameter	<0.0001	0.0762	0.9305
Flower diameter change rate	0.0906	0.4664	0.7265
Relative fresh weight	<0.0001	0.4342	0.4813
Stem water content (day 9)	—	<0.0001	—
Overall solution absorption rate	<0.0001	0.3412	0.4626
Daily solution absorption rate	<0.0001	0.9119	0.6149
Quality rating	<0.0001	<0.0001	<0.0001
Flower mean brightness (without ultraviolet)	<0.0001	<0.0001	<0.0001
Flower maximum brightness (without ultraviolet)	<0.0001	<0.0001	0.0639
Flower mean brightness (with ultraviolet)	<0.0001	0.0043	<0.0001
Flower maximum brightness (with ultraviolet)	0.0771	0.4083	0.4507
Vase brightness mean	—	<0.0001	—
Vase brightness maximum	—	1.0000	—

treatment interaction (Table 1). Flower mean brightness with UV for the reference glow-in-the-dark star was 85, which was 56% greater than the greatest treatment mean across all dates (data not shown). Flower mean brightness without UV was greatest 1 DAT, and brightness from all treatments, except the control, was reduced by 30% to 60% by 5 DAT (Fig. 2). The 6 s paint treatment resulted in the greatest flower mean brightness through 4 DAT, although this was not different from 6 s paint + 3 drops highlighter 1 DAT, 6 s paint + 3 drops highlighter and 4 s paint + 3 drops highlighter 3 DAT, and 6 s paint + 3 drops highlighter and 4 s paint 4 DAT.

Similarly, flower mean brightness with UV for the 6 s paint treatment was greater than the 1 drop highlighter 4 DAT, whereas no treatment differences were seen on any other day (Fig. 3). For all paint treatments, alone or in combination with highlighter, flower mean brightness with UV increased from 2 DAT through 4 DAT before decreasing by 10% to 40% from the peak to 5 DAT. However, for highlighter treatments, the peak for flower mean brightness with UV was reached 2 or 3 DAT and a decrease was observed thereafter. Use of UV light resulted in greater flower mean brightness for all treatments except the control (Figs. 2 and 3).

With regard to quality rating, the 6 s paint treatment was greater than the 2 s paint at 7 DAT (Fig. 4). On 8, 9, and 10 DAT, the 6 s paint + 3 drops highlighter was greater than the 1 drop highlighter. Highlighter alone showed less of an effect on visual deterioration than paint or a combination of paint and highlighter. The 6 s paint and 6 s paint + 3 drops highlighter had a deterioration score of 2 points at 6 DAT, whereas the control did not reach a rating score of 2

Fig. 2. Treatment $\times$ day interaction effect for the flower mean brightness [without ultraviolet (UV)] charge of carnations using glow-in-the-dark spray paint or yellow highlighter at different rates. The significant difference among treatments on a specific day is represented by an asterisk.

Fig. 3. Treatment $\times$ day interaction effect for the flower mean brightness [with ultraviolet (UV)] charge of carnations using glow-in-the-dark spray paint or yellow highlighter at different rates. The significant difference among treatments on a specific day is represented by an asterisk.

points until 9 DAT. At 9 DAT, all treatments except 1 drop highlighter, 3 drops highlighter, and the control had a deterioration score of 3 points or more.

Significant day effects were seen for stem fresh weight, flower diameter, relative fresh weight, daily solution absorption rate, overall solution absorption rate, and flower maximum brightness without UV (Table 1). Stem fresh weight, relative stem fresh weight, flower diameter, and overall solution absorption rate increased each day until peaking 4 DAT before initiating a steady decline (Table 2). Daily solution absorption was negative for the first 4 DAT before

increasing to positive values for the remainder of the study. Rates from 6 through 10 DAT were significantly greater than those during the first 4 d. Flower maximum brightness without UV was greatest 2 DAT, but was significantly different from that on 3, 4, and 10 DAT (Table 2).

Significant treatment effects were seen for stem dry weight, stem water content, flower maximum brightness without UV, and vase flower mean brightness (Table 1). For stem dry weight, the 4 s paint treatment was greater than the half-stick highlighter treatment, whereas all other means were similar (Table 3). Stem water content for the control was greater than that for the 4 s paint treatment, but other means were similar (Table 3). Flower maximum brightness among treatments was greatest for the 6 s spray paint (110.49), which was 26% less than the reference glow-in-the-dark star (Table 3). None of the highlighter-alone treatments nor the control showed luminescence without UV charge (Table 3). Vase mean brightness was greatest for the half-stick highlighter treatment, whereas none of the spray paint-alone treatments nor the control showed any vase glow (Table 3). Luminescence duration was greatest for 6 s paint (6 h), whereas 2 s paint lasted twice as long as any of the highlighter treatments (1 h) (data not shown).

Discussion

Condition of the flower is the most important consideration with respect to consumer acceptance and thus vase life, which is determined by the number of days from harvest until flower senescence (Ebrahimzadeh et al., 2008; Wernett et al., 1996). Average carnation vase life is known to vary among cultivars and harvest age from 7 to 14 d, and is indicated by petal in-rolling and wilting as a

Fig. 4. Treatment $\times$ day interaction effect for the browning deterioration scale of carnations using glow-in-the-dark spray paint or yellow highlighter at different rates. The significant difference among treatments on a specific day is represented by an asterisk.

result of increased respiration and ethylene production and decreased water absorption (Ebrahimzadeh et al., 2008; Satoh et al., 2005; Wu et al., 1991). All treatments except 1 drop highlighter, 3 drops highlighter, half stick, and the control had a quality rating of 2 points by day 8 and a rating of 3 points by day 9, indicating reduced vase life (Fig. 4). Although not significantly different from other treatments, the control did not have a rating of 3 points until day 11. Previous studies also reported that use of dyes on cut rose (*Rosa hybrida* L.), gerbera (*Gerbera jamesonii* L.), carnation, and gladiolus (*Gladiolus communis* L.) stems has shown a 1- to 3-d shorter vase life than the control (Shim et al., 2012; Sneha et al., 2019). The possible reason for this could be that use of spray paint or highlighter strongly affected the antioxidant defense system and resulted in decreased vase life (Aalifar et al., 2020).

Paint treatments and paint plus highlighter showed 0.5 to 1 value greater deterioration ratings corresponding to reduced vase life regardless of concentration compared with

the control and 1 drop and 3 drop highlighter-alone treatments (Fig. 4). In contrast, Safeena et al. (2016) used six different edible dyes on tuberose (*Polianthes tuberosa* L.) ‘Mexican Single’ and ‘Pearl Double’ and reported no adverse effect of dye concentration or immersion time on vase life and quality. Similarly, the results from our current study show that the use of highlighter solution alone does not appear to be as toxic to the flowers as the paint, at least at lower rates, as the highlighter solution was left in the vase water for the duration of the experiment and no differences were seen among controls for vase life. Sneha et al. (2019) examined six different food dyes on cut gerbera, carnation, and gladiolus stems and reported that a longer soak time (7.5 h) resulted in brighter flowers but reduced vase life.

The maintenance of water relations and good water absorption are important factors for vase life of cut flowers (Slootwet, 1995; van Meeteren and Aliniaiefard, 2016). In our study, stem fresh weight, relative stem fresh weight, and overall solution absorption rate increased though 4 DAT then declined

(Table 2). Wu et al. (1991) also found that carnation ‘White Sim’ and ‘Sandra’ flower fresh weight increased during the first 4 d in the vase, whereas ‘Chinera’ increased for 6 d before declining. Ranchana et al. (2017) used the stem absorption method to tint China aster [*Callistephus chinensis* (L.) Nees] ‘Local White’ with food dyes and reported vase life to only be 1 d vs. 7 d for the control as a result of wilting and reduced water absorption. Decrease in water absorption may have been caused by microbial growth, deposition of materials such as gums and mucilage in the lumen of xylem vessels, formation of tyloses, the presence of air emboli in the vascular system, or programmed cell death (van Doorn, 1997).

Although stem water content was lowest for 4 s paint, the difference was probably the result of the scale more than a treatment effect (Table 3). Reynolds et al. (2016) reported reduced transpiration of bermudagrass [*Cynodon dactylon* (L.) Pers $\times$ *C. transvaalensis* Burt Davy] ‘Tifway’ as a result of weekly colorant paint treatments resulting from blocked gas exchange through stomata. Therefore, any reductions in gas exchange would reduce transpiration and water absorption, resulting in petal browning. Koohkan et al. (2014) reported no difference in carnation ‘Miledy’ flower diameter when stems were treated with silver nanoparticles. This was likely a result of stems initially being sorted based on uniformity, whereas in our study all stems were used. They further reported a decline in flower diameter after 6 d, and no difference among treatments for relative fresh weight but differences within days, which is similar to our data.

Highlighter dye absorption took 4 d for green luminescence to show under black light (Fig. 4). In contrast, Sowmeya et al. (2017) reported dye absorption in carnation can occur within an hour. Thus, absorption of the highlighter may have occurred sooner, but it took several days for concentrations to accumulate to show up under UV light. Greater application rates of spray paint only led to greater brightness initially before UV charge, but not after UV charge, in contrast to highlighter dye, which did have greater glow with increased concentration on 2 and 10 DAT (Figs. 2 and 3). Safeena et al. (2016) found

Table 2. Main effects of days on stem and flower characteristics, water relations, and brightness after application of glow-in-the-dark spray paint and yellow highlighter dye to cut-flower carnations at the Greenhouse Learning Center, Headhouse (Stillwater, OK) in 2021.

Day	Stem fresh wt (g)	Relative stem fresh wt (%)	Flower diam (mm)	Overall solution absorption rate (%)	Daily solution absorption rate (g)	Flower maximum brightness (without ultraviolet)
1	16.82 de	—	48.80 f ^a	—	—	98.71 a
2	18.14 c	108.03 c	71.07 b	8.03 b	−0.08 d	104.10 a
3	18.98 b	113.13 b	63.06 d	13.18 a	−0.05 c	79.04 bc
4	19.25 a	114.70 a	76.84 a	14.74 a	−0.01 c	78.17 bc
5	19.02 ab	112.46 b	76.81 a	12.75 a	0.02 bc	91.72 a
6	18.27 c	100.14 de	75.42 a	9.17 b	0.04 ab	85.09 a
7	17.17 d	102.58 d	70.75 b	2.58 c	0.06 a	94.85 ab
8	16.43 e	98.27 e	65.82 c	−1.80 d	0.04 ab	99.48 ab
9	15.34 f	91.72 f	61.29 d	−8.28 e	0.07 a	89.16 ab
10	14.12 g	84.89 g	58.12 e	−15.76 f	0.07 a	50.43 c
11	13.55 h	82.18 g	59.31 de	−19.21 f	0.02 a–c	—

^aMeans (n = 15) within a column followed by the same letter are not significantly different by Tukey’s pairwise comparison ($P < 0.05$).

Table 3. Main effects of treatments on stem characteristics and brightness on cut-flower carnations in a controlled environment room at the Greenhouse Learning Center headhouse (Stillwater, OK) in 2021.

Treatment	Stem dry wt (g)	Stem water content (g)	Maximum brightness (without ultraviolet)	Vase brightness mean
Spray paint (2 s) ^z	2.53 ab ^y	0.83 ab	78.10 b	0 c
Spray paint (4 s)	2.67 a	0.81 b	91.02 b	0 c
Spray paint (6 s)	2.47 ab	0.83 ab	110.49 a	0 c
Highlighter (1 drop) ^x	2.20 ab	0.85 ab	0 c	36.32 b
Highlighter (3 drops)	2.20 ab	0.86 ab	0 c	43.27 b
Highlighter (1/2 stick)	2.07 b	0.86 ab	0 c	95.38 a
Highlighter (3 drops) + spray paint (2 s)	2.40 ab	0.83 ab	73.75 b	46.63 b
Highlighter (3 drops) + spray paint (4 s)	2.47 ab	0.84 ab	81.35 b	47.66 b
Highlighter (3 drops) + spray paint (6 s)	2.47 ab	0.83 ab	87.71 b	45.61 b
Control	2.33 ab	0.87 a	0 c	0 c
Standard ^w	—	—	148.00	—

^zGlow-in-the-dark spray paint (Rust-Oleum Corporation, Vernon Hills, IL).

^yMeans (n = 15) within a column followed by the same letter are not significantly different by Tukey's pairwise comparison ($P < 0.05$).

^xYellow highlighter (Staples the Office Store, Farmingham, MA).

^wA glow-in-the-dark star (MLM, Amazon, Seattle, WA).

that greater immersion (24 h) at the maximum concentration (1.5%) allowed more dye to be translocated throughout tuberose flowers. Byun et al. (2004) reported that an increased dyeing time of rose 'Taeinhe' with artificial blue and green pigments resulted in a darker color.

Flower maximum brightness with UV was reduced significantly 3, 4, and 10 DAT, likely as a result of exposure time to fluorescent light, and reduced coverage on 10 DAT resulting from flower wilting (Fig. 3). Khat-tab et al. (2019) reported strontium aluminate phosphor combined with divalent europium phosphorescence intensity peaked 5 min after UV charge, then showed a steep decline before stabilizing 9 min after the UV charge. Peak luminescence is known to last only a few minutes, so flower mean brightness is likely a better indicator of overall flower luminescence value. For flower mean brightness with UV, all spray paint, highlighter, and combination treatments increased from 2 through 4 DAT before decreasing by 50% from the peak by 5 DAT (Fig. 3). The decrease was the result of a change in picture angle. For 2, 3, and 4 DAT, analyzed images included artifacts of the UV light source itself, which caused some interference in flower analysis. Thus, 5 DAT, the picture angle was adjusted to block the UV light, resulting in superior analysis of the flowers themselves. Any future studies should block the UV light if using similar methods to quantify brightness. Swart et al. (2012) reported that phosphor intensity can decrease 20% over a period of 2 weeks under UV radiation, which is similar to the decline observed in our study after 10 d ($\approx 35\%$ without UV, $\approx 12\%$ with UV).

Conclusion

Both spray paint and highlighter dye could be used by florists as a tinting method to create a novel, value-added product. Choice of treatment is likely dependent on preference or product limitations, although there is no added benefit of using them in combination except for vase glow. Use of UV light increased brightness and was required for luminescence of highlighter-only

treatments. The 1-drop highlighter treatment is recommended over greater highlighter-only rates based on the limited benefit in terms of brightness at greater rates and lower quality ratings observed 8 DAT. Among spray paint treatments, 6 s paint resulted in the greatest brightness response without worsening the deterioration rate compared with lower rates. Spray paint provided the greatest flexibility because it worked with and without UV light, had immediate luminescence, was brighter after UV exposure, and had a longer brightness duration. Future research should investigate different chemicals and colors of glow-in-the-dark powders, effects on different species and flower colors, and rates that maximize brightness and flower vase life.

Literature Cited

- Aalifar, M., S. Aliniaefard, M. Arab, M.Z. Mehrjerdi, S.D. Daylami, M. Serek, E. Woltering, and T. Li. 2020. Blue light improves vase life of carnation cut flowers through its effect on the antioxidant defense system. *Frontiers Plant Sci.* 11:511, <https://doi.org/10.3389/fpls.2020.00511>.
- Byun, M.-S., J.-W. Kim, and K.-W. Kim. 2004. Effect of artificial dyeing on ornamental value and vase life in cut flower of *Rosa hybrida* cv. Taeinhe. *Korean J. Hort. Sci. Technol.* 22: 114–118.
- Chandler, S. and Y. Tanaka. 2007. Genetic modification in floriculture. *Crit. Rev. Plant Sci.* 26:169–197, <https://doi.org/10.1007/s10529-010-0424-4>.
- Chang-li, Z., L. Li, and X. Guo-quan. 2011. The physiological responses of carnation cut flowers to exogenous nitric oxide. *Scientia Hort.* 127:424–430, <https://doi.org/10.1016/j.scienta.2010.10.024>.
- Chiatti, C., C. Fabiani, F. Cotana, and A.L. Pisello. 2021. Exploring the potential of photoluminescence for urban passive cooling and lighting applications: A new approach towards materials' optimization. *Energy* 231:120815, <https://doi.org/10.1016/j.energy.2021.120815>.
- Cubitt, A.B., R. Heim, S.R. Adams, A.E. Boyd, L.A. Gross, and R.Y. Tsien. 1995. Understanding, improving and using green fluorescent proteins. *Trends Biochem. Sci.* 20:448–455, [https://doi.org/10.1016/s0968-0004\(00\)89099-4](https://doi.org/10.1016/s0968-0004(00)89099-4).
- Ebrahimzadeh, A., S. Jiménez, J.A. Teixeira da Silva, S. Satoh, and M.T. Lao. 2008. Postharvest physiology of cut carnation flowers. *Fresh Prod.* 2:56–71.
- Hamidimoghadam, E., V. Rabiei, A. Nabigol, and J. Farrokhi. 2014. Postharvest quality improvement of carnation (*Dianthus caryophyllus* L.) cut flowers by gibberellic acid, benzyl adenine and nano silver. *Agr. Comm.* 2:28–34.
- He, S.G., D.C. Joyce, D.E. Irving, and J.D. Faragher. 2006. Stem-end blockage in cut *Grevillea* 'Crimson Yul-lo' inflorescences. *Postharvest Biol. Technol.* 41:78–84, <https://doi.org/10.1016/j.postharvbio.2006.03.002>.
- Heins, R.D. and N. Blakely. 1980. Influence of ethanol on ethylene biosynthesis and flower senescence of cut carnation. *Scientia Hort.* 13:361–369, [https://doi.org/10.1016/0304-4238\(80\)90094-1](https://doi.org/10.1016/0304-4238(80)90094-1).
- Hu, C.D. and T.K. Kerppola. 2003. Simultaneous visualization of multiple protein interactions in living cells using multicolor fluorescence complementation analysis. *Nat. Biotechnol.* 21: 539–545.
- Hunter, N.T. 2012. *The art of floral design*. 3rd ed. Cengage Learning, Boston, MA.
- Kendall, J.M. and M.N. Badminton. 1998. *Aequora victoria* bioluminescence moves into an exciting new era. *Trends Biotechnol.* 16:216–224, [https://doi.org/10.1016/s0167-7799\(98\)01184-6](https://doi.org/10.1016/s0167-7799(98)01184-6).
- Khattab, T.A., A.M. Gabr, A.M. Mostafa, and T. Hamouda. 2019. Luminescent plant root: A step toward electricity-free natural lighting plants. *J. Mol. Struct.* 1176:249–253, <https://doi.org/10.1016/j.molstruc.2018.08.101>.
- Koohkan, F., N. Ahmadi, and S.J. Ahmadi. 2014. Improving vase life of carnation cut flowers by silver nano-particles acting as anti-ethylene agent. *J. Appl. Hort.* 16:210–214, <https://doi.org/10.37855/jah.2014.v16i03.34>.
- Kraemer, H. 1905. Artificial coloring of flowers. *Torrey* 5:211–213.
- Labno, C. n.d. Basic intensity quantification with ImageJ. University of Chicago. 19 Oct. 2021. <<https://www.unige.ch/medecine/bioimaging/files/1914/1208/6000/Quantification.pdf>>.
- Li, Y. and Y. Pei. 2006. *Plant biotechnology in ornamental horticulture*. Haworth Food and Agricultural Products Press, New York, NY.
- Lou, X., M. Anwar, Y. Wang, H. Zhang, and J. Ding. 2021. Impact of inorganic salts on vase life and postharvest qualities of the cut flower of perpetual carnation. *Braz. J. Biol.* 81:228–236, <https://doi.org/10.1590/1519-6984.221502>.
- Maitra, S. and N. Roychowdhury. 2013. Performance of different standard carnation (*Dianthus caryophyllus* L.) cultivars in the plains of West Bengal, India. *Intl. J. Bio-resource Stress Mgt.* 4:395–399.
- McCarty, R., B.L. Dunn, C. Fontanier, and M. Beartrack. 2019. Reduction of plant quality and

- photosynthesis of *Spathiphyllum* 'Petite' using glow-in-the-dark paint. *HortScience* 54:S388 (abstr).
- Mekala, P., M. Ganga, and M. Jawaharlal. 2012. Artificial colouring of tuberose flowers for value addition. *South Indian Hort.* 60:216–223.
- Mercuri, A., A. Sacchetti, L. De Benedetti, T. Schiva, and S. Alberti. 2002. Green fluorescent flowers. *Plant Sci.* 162:647–654, [https://doi.org/10.1016/S0168-9452\(02\)00044-4](https://doi.org/10.1016/S0168-9452(02)00044-4).
- Nelson, P. 2012. *Greenhouse operation and management*. Pearson Prentice Hall, Upper Saddle River, NJ.
- Nelson, C. 2016. Beautiful untrue things: Green carnations and the art of dyeing. *The Wildean* 48:96–103.
- Nesbit, A.A. 1882. Notes on experiments of the absorption of dyes by flowers'. *J. Sci.* 19: 430–432.
- Nowak, J. and R. Rudnicki. 1990. *Postharvest handling and storage of cut flowers, florist greens, and potted plants*. Timber Press, Portland, OR.
- Pérez-Clemente, R.M., A. Pérez-Sanjuán, and L. García-Ferriz. 2004. Transgenic peach plants (*Prunus persica* L.) produced by genetic transformation of embryo sections using the green fluorescent protein (GFP) as an in vivo marker. *Mol. Breed.* 14:419–427.
- Poelman, D., D. Van der Heggen, J. Du, E. Cosaert, and P.F. Smet. 2020. Persistent phosphors for the future: Fit for the right application. *J. Appl. Phys.* 128:240903, <https://doi.org/10.1063/5.0032972>.
- Ranchana, P., M. Ganga, M. Jawaharlal, and M. Kannan. 2017. Standardization of tinting techniques in China aster cv. Local White. *Intl. J. Current Microbiol. Appl. Sci.* 6:27–31, <https://doi.org/10.20546/ijemas.2017.609.003>.
- Reid, M.S., J.L. Paul, M.B. Farhoomand, A.M. Kofranek, and G.L. Staby. 1980. Pulse treatments with silver thiosulfate complex extends the vase life of cut carnations. *J. Amer. Soc. Hort. Sci.* 105:25–27.
- Reynolds, W.C., G.L. Miller, D.P. Livingston, III, and T.W. Ruffy. 2016. Athletic field paint color impacts transpiration and canopy temperature in bermudagrass. *Crop Sci.* 56:2016–2025, <https://doi.org/10.2135/cropsci2016.01.0028>.
- Sacchetti, A., R. Ciccocioppo, and S. Alberti. 2000. The molecular determinants of the efficiency of green fluorescent protein mutants. *Histol. Histopathol.* 15:101–107, <https://doi.org/10.14670/HH-15.101>.
- Safeena, S.A., M. Thangam, and N.P. Singh. 2016. Value addition of tuberose (*Polianthes tuberosa* L.) spikes by tinting with different edible dyes. *Asian J. Res. Biol. Pharm. Sci.* 4:89–98.
- Satoh, S., H. Nukui, and T. Inokuma. 2005. A method for determining the vase life of cut spray carnation flowers. *J. Appl. Hort.* 7:8–10.
- Schneider, C.A., W.S. Rasband, and K.W. Eliceiri. 2012. NIH Image to ImageJ: 25 Years of image analysis. *Nat. Methods* 9:671–675, <https://doi.org/10.1038/nmeth.2089>.
- Sedaghatpour, S., Z. Narouei, S.A. Sajjadi, and S. Piri. 2020. The effect of chemical treatments (silver thiosulfate and putrescine) on vase life and quality of cut *Chrysanthemum morifolium* (Ram.) flowers. *Cogent Biol.* 6:1, <https://doi.org/10.1080/23312025.2020.1754320>.
- Shim, A.I., Y.-J. Hwang, S.H. Bae, B.-G. Son, W.-C. Park, S.T. Kim, H.-K. Shin, H.-G. Ahn, and K.-B. Lim. 2012. Artificial dyeing of cut rose 'Akito' by absorption dyes. *Flower Res. J.* 20:223–227, <https://doi.org/10.11623/fj.2012.20.4.223>.
- Slootwet, G. 1995. Effect of water temperature on water absorption and vase life of cut spikes of gladiolus. *Plant Growth Regulat.* 55:221.
- Sneha, M., L. Kukanoor, S.R. Patil, M. Shiragur, M. Naik, K.S. Thippanna, and K.R. Naik. 2019. Standardization of tinting techniques in gerbera, carnation and gladiolus. *Intl. J. Chem. Stud.* 7:1153–1157.
- Sowmeya, S., S. Kumaresan, and L. Priya. 2017. Effect of multi colours in tinting techniques in cut flowers (rose and carnation). *Chem. Sci. Rev. Lett.* 6:2250–2253.
- Swart, H.C., J.J. Terblans, O.M. Ntwaeaborwa, R.E. Kroon, and B.M. Mothudi. 2012. PL and CL degradation and characteristics of SrAl₂O₄: Eu²⁺, Dy³⁺ phosphors. *Physica B* 407:1664–1667, <https://doi.org/10.1016/j.physb.2011.09.112>.
- To, K.Y. and C.K. Wang. 2006. Molecular breeding of flower color, p. 300–310. In: J.A.T. Silva (ed.). *Floriculture, ornamental and plant biotechnology: Advances and topical issues*. Global Science Books, London.
- van Doorn, W.G. 1997. Water relations of cut flowers. *Hort. Rev.* 18:1–85.
- van Meeteren, U. and S. Aliniaifard. 2016. Stomata and postharvest physiology in postharvest ripening, p. 157–216. In: S. Pareek (ed.). *Physiology of crops*. CRC Press, Boca Raton, FL.
- Wang, K., L. Kang, A. Anand, G. Lazarovits, and K.S. Mysore. 2006. Monitoring in planta bacterial infection at both cellular and whole-plant levels using the green fluorescent protein variant GFPuv. *New Phytol.* 174:212–223, <https://doi.org/10.1111/j.1469-8137.2007.01999.x>.
- Wernett, H.C., T.J. Sheenan, G.J. Wilfret, F.J. Marousky, P.M. Lyrene, and D.A. Knauff. 1996. Postharvest longevity of cut-flower gerbera: I. Response to selection for vase life components. *J. Amer. Soc. Hort. Sci.* 121:216–221, <https://doi.org/10.21273/JASHS.121.2.216>.
- Wu, M.J., W.G. van Doorn, and M.S. Reid. 1991. Variation in the senescence of carnation (*Dianthus caryophyllus* L.) cultivars: I. Comparison of flower life, respiration and ethylene biosynthesis. *Scientia Hort.* 48:99–107, [https://doi.org/10.1016/0304-4238\(91\)90156-S](https://doi.org/10.1016/0304-4238(91)90156-S).
- Zhang, J., R.E. Campbell, A.Y. Ting, and R.Y. Tsien. 2002. Creating new fluorescent probes for cell biology. *Nat. Rev. Mol. Cell Biol.* 3:906–918, <https://doi.org/10.1038/nrm976>.