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Blue Phosphorescence of Standard Cut Flower Carnation

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***Abstract.* An experiment was conducted to quantify luminescence of white cut flower carnations after exposure to blue glow-in-the-dark powder. Powder was applied to the flowers as either dip (3, 6, or 9 g) or spray (3, 6, or 9 g) solutions in 240 mL of water for 4 seconds plus a control. Stem fresh weight, relative stem fresh weight, flower diameter, and overall solution absorption were greatest on day 4. Only the 6-g dip or spray had greater average flower quality ratings than the control, indicating reduced vase life, but there was no difference among powder treatments. Phosphorescence is possible with fluorescent light, but ultraviolet light increased the flower mean brightness an average of 75% across all treatments. No treatment differences were observed for the flower mean brightness with ultraviolet light, except on day 9; however, greater powder rates without ultraviolet light in general resulted in greater brightness.**

Luminescence is when light is emitted by an object given an energy source; however, the light disappears as soon as excitation ends. Glow-in-the-dark products, such as paints or powders, comprise a type of luminescence called photoluminescence, which is the production of light from the absorption of photons and subsequent excitation. The amount of light that persists after excitation is phosphorescence, which can last several minutes to hours (Murthy and Virk, 2013; Valeur and Berberan-Santos, 2011).

There is interest in luminescence as it relates to plants. Genetic engineering studies have used green fluorescent protein in plants for novelty and gene reporter technology (Mercuri et al., 2002; Zimmer, 2002). The protein can also be used as a fluorescent tag for interaction, localization, and identification in plants (Chiu et al., 1996). A study developed glow-in-the-dark cotton clothing from the use of lanthanide-doped strontium aluminate, which possesses a long period of glow from excitation and storage ability when exposed to a light source (Khattab et al., 2019b). Khattab et al. (2019a) found that some plants are able to uptake luminescent chemicals as an initial step toward electricity-free natural light. Recently, a study involving green glow-in-the-dark spray paint and yellow highlighters on carnations as a value-added product was performed (Pace et al., 2022). Although both products worked, there were limitations of only obtaining green luminescence. This study evaluated blue luminescent powder as an alternative material that could provide a different luminescent color for use by the floral industry.

Material and Methods

Standard carnation (*Dianthus caryophyllus* L.) cut flowers were received in a cooler set at 3.3 °C from Bear Creek Farms (Stillwater, OK) on 17 June 2021. Stems were cut to 40 cm at a 45-degree angle, and leaves were removed from the lower 10 cm of the stem. The carnations were placed into fluted glass bud vases, with one flower per vase, filled with 240 mL of deionized water and 2 g of floral preservative (Syndicate Sales Inc., Kokoma, IN), including the control, from 17 June 2021 through 27 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 with fluorescent light. On 17 June 2021, treatments comprising 3, 6, or 9 g of blue glow-in-the-dark powder (ProCart; SC ALBACOM Biz SRL, Alba Lulia, Romania) and 240 mL of deionized water were mixed and sprayed for 4 s using a standard spray bottle (Walmart, Bentonville, AR). Finally, 3, 6, or 9 g of the powder was mixed with 240 mL of water, and flowers were dipped in the mixture for 4 s. A control that did not receive any powder treatments was also used during the experiment. Each treatment was applied to a set of three stems and replicated five times, resulting in 15 vases per treatment. The vases were arranged in a completely randomized design.

Measurements were performed daily to obtain the stem weight (combined weight of stem and flower), vase weight, average flower diameter (average of two perpendicular measurements), and visual deterioration. The relative fresh weight percent, water content, flower diameter change rate, overall solution absorption rate, and daily solution absorption rate were calculated according to Pace et al. (2022). Visual deterioration was evaluated using a rating score (average daily rating per day) of 1 to 4 for deterioration (1, no browning; 2, browning around the edges; 3, some browning throughout the flower; 4, complete browning and shriveled flower) to represent the quality.

To quantify brightness, images of flowers in darkness were obtained using a smartphone camera (iPhone XS Maximum; Apple, Cupertino, CA). Images were collected before black light exposure (flower mean without ultraviolet) and again while a 365-nm black light was used (Sunlite Industrial Corp., El Monte, CA); the results were reported as the flower mean with ultraviolet light. Photos were analyzed for brightness using ImageJ (Schneider et al., 2012) version 1.53j; the mean brightness between 0 and 255 of the outlined phosphorescent flower was measured (Labno, n.d.). A photo of tonic water (Great Value; Walmart, Bentonville, AR) in a clear beaker was used as the standard. The experiment was concluded on 27 June 2021, after all flowers had a quality rating of 4.

A 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 level. The data were analyzed using the generalized linear mixed models methods. Tukey's multiple comparison methods were used to separate the means.

Results and Discussion

The flower mean brightness (with ultraviolet light) showed a significant day × treatment interaction ($P < 0.0006$). For all treatments, the greatest values (23 to 35) were observed 1 d after treatment (DAT), and all treatments except the 3-g dip, which showed a decreasing trend over time, showed a cyclic increasing and decreasing trend over time (data not shown). Brightness values were likely influenced by the application consistency and water droplet size, which might have benefitted from the use of a surfactant for even distribution. Surfactants are commonly used in flower preservative solutions and help to quickly rehydrate flowers because they reduce the surface tension of water (Seyed et al., 2012). The differences with the 6-g spray treatment were greater than those observed with the 3-g dip at 9 DAT; however, no treatment differences were observed on any other day. The use of ultraviolet light resulted in greater flower mean brightness for all treatments except the control, with values ranging from 8 to 35. Ultraviolet light, with high-energy photons, is most effective at charging light traps, resulting in persistent and greater luminescence (Poelman et al., 2020). The reference tonic water with ultraviolet light exposure was 78, which was twice the greatest mean treatment value and 15-times greater than the lowest treatment mean across all dates.

Significant day effects on stem fresh weight ($P < 0.0001$), relative stem fresh weight ($P < 0.0001$), flower diameter ($P < 0.0001$), overall solution absorption rate ($P < 0.0001$), daily solution absorption rate ($P < 0.0001$), flower mean brightness (without ultraviolet) ($P < 0.0001$), and quality rating ($P < 0.0001$) were observed. Stem fresh weight, relative stem fresh weight, flower diameter, and overall solution absorption rate increased each day and peaked on 4 DAT; thereafter, a steady decline

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Table 1. Main effects of days on stem and flower characteristics, water relations, and brightness after application of blue glow-in-the-dark powder either dipped and sprayed on 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 mean brightness (without ultraviolet)	Quality rating[i]
1	15.25 cd[ii]		48.68 f			12.40 a	1.00 h
2	16.46 ab	108.50 b	67.07 c	8.50 b	−0.09 d	8.15 b	1.02 gh
3	16.83 a	111.55 a	73.53 a	11.55 a	−0.03 c	8.85 b	1.16 gh
4	16.91 a	112.36 a	73.94 a	12.36 a	−0.01 bc	9.08 b	1.29 g
5	15.90 bc	106.40 b	71.26 b	6.40 b	0.06 a	8.36 b	1.64 f
6	14.90 d	100.14 c	67.28 c	0.14 c	0.06 a	8.09 b	2.35 e
7	13.83 e	93.57 d	62.26 d	−8.74 d	0.08 a	9.09 b	3.09 d
8	13.21 f	90.60 de	59.18 de	−13.08 d	0.05 a	9.08 b	3.41 c
9	12.45 g	86.92 e	57.13 e	−14.18 d	0.06 a	9.18 b	3.60 bc
10	12.07 g	83.79 e	58.17 de	−14.02 d	0.03 ab		3.76 ab
11							3.95 a

[i] 1, no browning; 2, browning around the edges; 3, some browning throughout the flower; 4, complete browning and shriveled flower.

[ii] Means (n = 15) within a column followed by the same lowercase letter are not significantly different according to the pairwise comparison using the mixed model ($P < 0.05$).

Table 2. Main effects of treatments on flower characteristics and brightness of cut flower carnations in a controlled environment room at the Greenhouse Learning Center headhouse (Stillwater, OK) in 2021.

Treatment[i]	Flower mean brightness (with ultraviolet)	Quality rating[ii]
Dip, 3 g	7.86 d[iii]	2.35 ab
Dip, 6 g	8.33 cd	2.48 a
Dip, 9 g	9.30 abc	2.41 ab
Spray, 3 g	8.88 bdc	2.43 ab
Spray, 6 g	10.51 a	2.47 a
Spray, 9 g	9.98 ab	2.33 ab
Control		2.24 b
Standard[iv]	78.19	

[i] ProCart glow-in-the-dark powder (SC ALBACOM Biz SRL, Alba Lulia, Romania) dipped or sprayed for 4 s.

[ii] 1, no browning; 2, browning around the edges; 3, some browning throughout the flower; and 4, complete browning and shriveled flower.

[iii] Means (n = 15) within a column followed by the same lowercase letter are not significantly different according to the pairwise comparison using the mixed model ($P < 0.05$).

[iv] Great Value tonic water (Walmart, Bentonville, AR).

occurred (Table 1). Pace et al. (2022) also reported similar results for carnation using yellow highlighter and green glow-in-the-dark paint. Daily solution absorption was negative for the first 4 DAT before increasing to positive and significantly greater values from 5 DAT through 10 DAT. Flower mean brightness (without ultraviolet) was greatest on 1 DAT; however, no difference was seen on any other day. The quality rating was lowest on 1 DAT, but it was not different from that on 2 DAT and 3 DAT. Quality rating scores increased over time and were 2 on 6 DAT and 3 on 7 DAT.

Significant treatment effects were seen for quality rating ($P < 0.0027$) and flower mean brightness (without ultraviolet) ($P < 0.0001$). Regarding the quality ratings, the control had the lowest quality rating, but it was not different from that of all other treatments except the 6-g dip or spray treatments (Table 2). Regarding flower mean brightness (with ultraviolet), the 6-g spray resulted in the greatest flower mean brightness, but it was not different from that of the 9-g dip or 9-g spray, whereas the lowest flower mean brightness was observed with the 3-g dip. The control did not show phosphorescence with or without ultraviolet light. Adding 3, 6, or 9 g to the vase water did not result in flower phosphorescence (data not shown).

Conclusion

The use of ultraviolet light increased the flower mean brightness, although differences among treatments were only observed on 9 DAT. In general, under florescent light, greater powder concentrations resulted in better phosphorescence; however, the 6-g dip or spray treatments had greater quality ratings, which corresponded to reduced vase life. Both spray and dip methods were effective, but spray resulted in more flowers with areas of heightened glow, likely because of residual water droplets, than dip. Future research should evaluate different glow-in-the-dark products, rates, light sources, and application methods among other species to optimize brightness while maintaining flower vase life.

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