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Gladiolus cut flower postharvest performance to direct breeding efforts

Neil O. Anderson*

Department of Horticultural Science, University of Minnesota, 1970 Folwell Avenue, Saint Paul, MN 55108 USA

* Corresponding author, E-mail: ander044@umn.edu

Abstract

Gladiolus is an important floricultural and nursery crop used for gardening and floral design. The lengthy, linear stems with large, brightly colored flowers make it a long-term favorite of floral designers. Vase life ranges from 6–10+ d, making this crop a mainstay in the floral industry. The objective of this research was to test a sample of 11 advanced cut flower selections and two cultivars with varying ancestry, plant stature, and floral traits to establish a norm for future breeding and selection criteria for development of a cut flower crop ideotype. Genotypes were tested in field production trials to establish their cut stem length, visible bud date, flowering date, duration of flowering, plant height and width, number of leaves, flower petal type, flower color and petal markings. Flower stems were harvested at stage 2 and then stored at 3–5 °C. Postharvest vase solution treatments were deionized, distilled water and FloraLife Crystal Clear Flower Food 300® floral preservative for 9 d, recording 18 traits related to the inflorescence, water uptake, pH changes, dry matter, flower opening/closure, and salability. In the production trials, flowering week and plant height were the only phenotypic traits with significance. Genotypes were significantly different for nearly all traits examined whereas treatments or their interactions were less so, providing selection potential for future crop improvements. Many traits were significantly correlated, which will provide for greater efficiency and selection potential. Future research will focus on heritability of these traits to provide a foundation of knowledge to create a gladiolus cut flower crop ideotype.

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Introduction

South Africa is the center of origin and diversity of gladiolus or sword lily, *Gladiolus* × *hybridus* Rodigas (Iridaceae), although species are also native in the Mediterranean (Italy, the Arabian Peninsula) and into the Russian Federation[1]. It is a major cut flower in the floriculture industry (ranked in the top ten cut flower crops), used as a line flower in line-mass designs[2] and sold in mixed or single cultivar bunches at retail farmer's markets or wholesale commercial floral markets, respectively. Gladiolus have been in the top ten cut flowers in Dutch auctions since 1958, with ~1 M gladioli stems/year sold[3]. In 2018, gladiolus corm production in the Netherlands was 637 ha and floral spike production 153 ha[4]. In 2020, the US value of cut flower gladiolus was US$14.83M (w, wholesale farmgate value)[5], while Chinese production of gladiolus is increasing[6]. In China, gladiolus production covered 3,300 ha in 2014 which made it the second-most grown geophyte in China after *Lilium*[7]. It is also grown as an ornamental garden plant (non-hardy, tender perennial in northern latitudes, USDA Z3-4)[8].

Gladiolus species are geophytic with corms (compressed stems) for underground storage organs[9]. In commercial production, gladioli are planted as 3–5 year-old corms, capable of flowering[10,11]. Gladioli are vegetatively propagated *via* daughter corms and/or cormels in commercial production. Daughter corms arise above the current season's mother corm; all corms and cormels arise from the daughter corm's basal plate and consist of an enlarged stem axis with nodes and internodes with dry, scale-like leaves forming a protective 'tunic'[12]. Thus, gladiolus have tunicate corms. Classically, one daughter corm is generated/year by the mother corm but cormel numbers vary from one to hundreds/corm, depending on the cultivar[12]. Cormels differ from daughter corms, being smaller and arising directly from the basal plate[12]). After corm/cormel sprouting, each propagule produces adventitious and contractile roots, the latter of which are thick fleshy roots which pull the seedling or corm deeper into the ground[13]. Seedlings form both root types and a small corm within 1–4 weeks post-germination immediately pulls the corm below the soil surface (N. Anderson & R. Eperjesi, 2019, unpublished data).

Gladiolus production is for either cut flower (floral design) purposes or for use as a garden annual/perennial[14], depending on the USDA Hardiness Zone since most are frost- and cold-sensitive in northern latitudes[8]. The floral spike (defined as the central stem with all individual florets)[1] is cut when petal coloration starts in the lowest floret but before it reaches anthesis[15], commercially referred to as Stage 2[11,16]. The florets open acropetally or from the base upwards in a linear fashion over time, 1x/day[10]. All commercial cut flower and garden cultivars are non-fragrant, although ten or more wild species have fragrance, including *G. orchidiflorus* (Anderson, 1999, unpublished data), *G. tristis* and *G. recurvus*[17].

Gladiolus stems are bunched in 5, 7 or 10 stems/bunch[16]. There are four grades (1–4) for minimum stem length 80–115 cm), minimum flower diameter (6.25–8.75 cm), stem strength (15°), stem deviation curvature from vertical (5–10 cm), and the minimum number of flowers or florets / stem (6–12)[10,11,16]. The

four major flower color classes of gladiolus are blue, yellow, red, and green although whites are commonly produced as well as novelty types with varying petal shapes, ruffled edges, etc.[16]. Gladiolus floral spikes can be stored dry or in floral preservative at 3–4 °C, 90% relative humidity for 2 to 3 weeks[10,16] At room temperature (20–22 °C), expected vase life is 7 d minimum. Gladiolus may have ethylene (C_2H_4) sensitivity during postharvest storage[16,18] necessitating treatment with either silver thiosulfate (STS) or 1-Methylcyclopropene (1-MCP)[19–21]. Ethylene response may reduce flower life by aborting unopened flower buds[21]. Prevention of ethylene buildup likewise increases postharvest longevity of gladiolus[18]. Gladiolus stem tips are negatively geotropic and are predominantly shipped/stored upright to prevent stem tip bending away from gravity[21].

Without floral preservatives, gladiolus may have shortened postharvest life due to lack of water from occlusions of basal stem cuts and microbial plugging of the xylem[2,10,19]. Sucrose (20%; overnight)[21,22] or cobalt[23] pulsing, as well as floral preservatives increase vase life of flower spikes as high as 12.3 d, although the range in vase life of a stem is 6–10 d[21]. Previous gladiolus cut flower postharvest research reported that higher temperatures during production decreased cut stem fresh weights, but the opposite was found with higher CO_2 levels[24].

Gladiolus breeding is primarily accomplished by amateur breeders in gladiolus societies, e.g. the North American Gladiolus Council[11], one private sector company (Breck's Holland)[25] and one public sector breeding program (University of Minnesota, USA)[8,26–28]. Many new cultivars are released each year using divergent ancestries[11,29]. In recent decades, significant corm production, postharvest and physiological research on gladiolus has been conducted in Brazil (Universidade Federal de Santa Maria, Santa Maria), Pakistan (The University of Agriculture, Faisalabad and Peshawar), India (Indian Agriculture Research Institute, New Delhi; University of Agricultural Science, Bangalore), Egypt (Kafrelsheikh University, Kafr El-Sheikh; Agricultural Research Center, Giza), Poland (University of Agriculture, Kraków), the Czech Republic (Mendelova zemědělská a lesnická univerzita v Brně, Brno) and Italy (Universita degli Studi di Bari, Bari). However, much of the production and postharvest techniques to achieve saleable product aren't translated into public or private sector breeding programs to aid in the advancement of the crop. To unite physiological and breeding/genetic research efforts, the University of Minnesota flower breeding program is developing cut flower cultivars with unique floral colors and patterns, along with cold tolerance for USDA Z3-4[8], rapid generation cycling (RGC)[21], dwarf types for potted plant and container production, and vegetative or seed-propagated F_1 hybrids. Most would be new traits for this crop and provide unique opportunities for postharvest testing to aid in breeding and selection. Thus, the objective of this research was to test a sample of advanced cut flower selections within the breeding program with varying ancestry, plant stature, and floral traits to establish baseline data for future breeding and selection for development of a gladiolus cut flower crop ideotype.

Materials and methods

This study was conducted at the public sector University of Minnesota Gladiolus Breeding & Genetics Program, involving greenhouse, laboratory, and field facilities in Saint Paul and Rosemount, Minnesota, USA.

Genotypes

Thirteen cut flower gladiolus genotypes were tested in this experiment. Eleven clonal genotypes (numbered selections, GL-1 to GL-11; Table 1) were hybrids or inbreds derived from the University of Minnesota breeding program plus two commercial named comparisons ('Beatrice', 'Manhattan'). Genotypes GL-1 to GL-11 were hybrids or inbreds produced from controlled crossings or selfs, respectively, in the St. Paul campus

Table 1. Hybrid gladioli of dwarf (< 90 cm) or tall stature (> 90 cm; Breck's Holland[25]) tested for field performance data (wk 22 planting dates), averaged over three years (2019, 2021, and 2022) grown under standard commercial field production trials in Rosemount, MN, USA for: number of weeks to visible bud date (VBD; VBD wk. no. – planting wk. no.), number of weeks to flowering (flowering wk. no. – planting wk. no.), number of weeks to termination of flowering (termination wk. no. – planting wk. no.), plant height (cm), plant width (cm), number of leaves, and flower petal type, flower color or petal markings.

Genotype	No. wks to VBD	No. wks to flowering, termination	Plant height (cm)	Plant width (cm)	No. of leaves	Flower petal type, flower color or petal markings
Dwarf stature (< 90 cm)						
GL-1	10	13 ab, 15	80.0 b	23.0	8	Slightly ruffled, peach, white venation
GL-2	12	15 b, 19	57.0 a	13.0	9	Hooded lt. pink/creamy white, yellow throat
Tall stature (> 90 cm)						
GL-3	12	13 ab, 15	91.5c	44.0	6	Ruffled red w/white throat
GL-4	10	12 a, 16	98.0 c	20.5	6	Fuchsia-red w/white streaked venation
GL-5	11	12 a, 14	101.0 cd	26.5	6	Dark orange
GL-6	11	13 ab, 16	115.0 d	36.0	8	Hooded cream w/yellow throat, red venation
GL-7	11	13 ab, 14	111.0 d	22	8	Red
GL-8	11	12 a, 16	93.0 c	25.0	8	Ruffled, red w/white throat
GL-9	10	12 a, 14	112.0 d	60.0	8	Ruffled red w/yellow throat
GL-10	10	14 ab, 16	117.2 de	16.5	8	Ruffled peach w/blotch (eye)
GL-11	12	14 ab, 16	121.0 de	53.0	8	Ruffled orange w/white throat
'Beatrice'	11	13 ab, 17	104.5 cd	27.6	8	Ruffled pink picotee, white w/yellow throat
'Manhattan'	10	12 a, 17	100.5 cd	43.5	8	Red
Significance	0.782 ns	0.034 *, 0.195 ns	0.001 ***	0.158 ns	0.166 ns	

Flowering termination week number was determined when > 50% of the flowers had senesced. Significance (*p*-values) were determined from univariate ANOVAs and mean separations derived from Tukey's Honestly Significantly Difference (HSD) test at $\alpha = 0.05$.

greenhouses (44°59'17.8" N lat., −93°10'51.6" W long.) during 2006−2016 or as open-pollinated (OP) seedlings in field trials. The OP seedlings were most likely inbreds, due to self compatibility operating in tetraploid gladioli. Seedling growouts to flowering (1−5 years) for subsequent clonal evaluation occurred in breeder field trials, Rosemount, MN (44°42'58.2'' N, −93°5'54.9" W)[27,28]. The short stature genotypes did not require staking or additional support in the field production (Fig. 1) whereas the taller ones did if the stems were left to completely flower (Fig. 2).

Field production experiments

Prior to the present study, these genotypes were tested for field performance data for three years (2019, 2021, and 2022) when grown under standard commercial field production trials; planting occurred during wk 22 (starting wk number). The tested genotypes were phenotypically categorized by stem length of either dwarf (< 90 cm) or tall statures (> 90 cm)[25] as well as for important production and postharvest traits, including visible bud date (VBD) week number, flowering week number, termination (of flowering) week number, plant height (cm), plant width (cm), number of leaves, flower petal type, flower color and petal markings (Table 1). Flowering termination week number was determined when > 50% of the flowe rs/stem had senesced.

In 2022, 3- to 5-year-old mature (capable of flowering) corms of the 13 selected genotypes for postharvest testing were grown in the fields. Corms were in the size grade ranges of 2.5 cm (Number 3) to 3.8 cm (Number 1), which ensured that all were capable of flowering[30]. As many as n = 30−100 clonal ramets of each genotype were grown for evaluation.

Cultural conditions for the cut flower gladiolus trial were similar to those used for other herbaceous annuals and perennials in the University of Minnesota breeder field[31], located at the University of Minnesota Rosemount Research and Outreach Center, Rosemount, MN, USA. In week 22 (29 May 2022), the n = 30−100 clonal ramets (corms) per accession were planted in spaced rows (7.6 cm on center or On Center (O.C.) within rows; 61.0 cm among rows) in a trenched system, completely randomized design. Corm depth burial was 7.6−10.2 cm, as per recommendations[30]. Field plots were fertilized with urea (56 kg/ha actual N, preplant granular) with hand weeding, mechanical tilling, and pre-emergent herbicide chemical applications for weed control (Fortress®, Isoxaben + Dithiopyr granular; 22.7 kg/0.4 ha; Amvac Chemical Corp., Bluffton, SC, USA). Overhead boom irrigation was used to supplement intermittent rainfall to ensure average precipitation of 2.54 cm/wk.

Postharvest experiment

Cut flower harvest occurred during wk 37 (2022), once all of the genotypes were at flowering stage with sufficient numbers of stems available for the postharvest study. Harvest was at Stage 2, when color was showing in the petals of the lower flowers[10,16]. Stems were cut in early morning (0700−0800 HRS), with 1/3 of the lower leaves were removed, followed by placement directly into standard 25 cm cooler buckets with deionized water. One genotype was placed in each cooler bucket (38.1 cm × 18 cm or 15" × 8"; www.koehlerdramm.com/pr/COOLER-BUCKET-15-X-8-BLACK/42576); once sufficient stems were harvested, the floral buckets were placed into shade for transport to the St. Paul campus once all the harvesting had occurred. Stems were immediately stored in a dark, walk-in cooler (3−5 °C) until the postharvest experiment began in < 24 h.

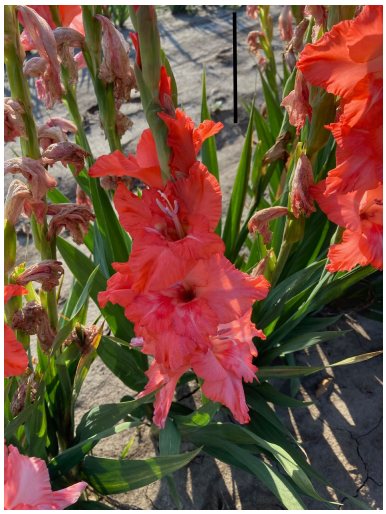

Fig. 1 Production field planting with an example nonlodging gladiolus genotype (GL-1). Scale: bar = 6 cm.

Fig. 2 Gladiolus cut flower stem lodging in the field production trials (GL-4), requiring staking or use of support mechanisms. Scale: bar = 6 cm.

Unlike previous studies where the stems were recut to the standard 75 cm length[19,32], the inclusion of dwarf stature (< 90 cm) types necessitated using different stem lengths (Fig. 3). Thus, each stem was recut (2 cm removed) prior to the start of the postharvest experiment[24].

The postharvest experiment was conducted during wks 37−38 (2022) in the laboratory at standard conditions of 24 h continuous light (10 μmol·sec^{-1}·m^{-2}) at 21 °C. Two solution treatments were tested: tested with two treatment solutions deionized, distilled water (DDW) and Floral Life floral preservative (FLFP; FloraLife Crystal Clear Flower Food 300® floral preservative; https://shop.floralife.com/) applied as continuous vase solutions. There were n = 6 (< 6 in some genotypes)

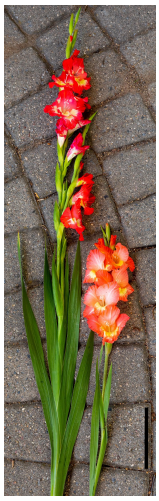

Fig. 3 Example cut tall (left) vs dwarf (right) glad stem lengths. Scale: bar = 14 cm.

replications/treatment solution/genotype, making a total of 13 genotypes × 2 treatments × 6 replications = 156 experimental units. Due to the size of the stems, large pedestal vases were used (24.765 cm, Syndicate Sales; https://directfloral.com/syndicate-sales-975-pedestal-vase-fiesta-assortment) and filled with 1.5 L of solution/vase. Vases were arranged in a completely randomized design (CRD) on the lab bench for the duration of the experiment; the experiment was conducted for 9 d.

Data collection

During the course of the experiment, the following parameters were measured, either at the beginning, ending or during the experiment: inflorescence cut stem length (cm), total no. of floret buds/stem, inflorescence internode length (cm), total no. (%) opened flowers, day 0 stem fresh weight (FW; g), day 9 stem FW (g), ΔFW (g; day 9 FW – day 0 FW), day 9 dry weight (DW; g), % water, 1st flower diameter (cm), 3rd flower diameter (cm), beginning and final pH, ΔpH, solution volume used per stem (ml), number of flowers senesced/day in days 1–9, total number of flowers senesced in days 1–9, and the number of saleable days (when the 5th floret from the base wilted; Fig. 4).

Statistical analyses

Data were analyzed with univariate general linear model Analysis of Variance (ANOVA) along with mean separations using Tukey's Honestly Significance Difference (HSD) tests at $\alpha = 0.05$ (Statistical Package for the Social Sciences, SPSS, version 22, University of Chicago, Chicago, IL, USA). Repeated measures ANOVA were used for parameters measured > 1x/stem. Pearson's correlations (r) of all traits were performed. Chi-square (χ^2) tests for equal distribution (1:1:1:1:1:1:1:1:1:1; df = 8; $\chi^2 = 15.507$) of the mean number of flowers senesced/day/genotype in days 1–9 and the total number of flowers sensed over the postharvest experiment period (days 1–9) were calculated.

Results

Field production experiments

All genotypes reached VBD within 10-12 wks from planting (Table 1) and were not significantly different. The range of VBD was within a 3-week range of calendar weeks 32 (GL-1, -4, -9, -10, 'Manhattan') to 34 (GL-2, -3, -11); other genotypes were at week 33. Significant differences were found, however, for flowering calendar week number, ranging from weeks 34 to 37 (Table 1) with the differences ranging from 12 (GL-4, -5, -8, -9, 'Manhattan') to 15 weeks from planting (GL-2; Table 1). Interestingly, GL-2 is a dwarf stature type that took significantly longer to flower than many other genotypes. In contrast, the number of weeks to flowering termination was not significant, with a range of 14–19 wks (Table 1). Genotypes have a flowering date range of 14 wks (98 d) to 19 wks (133 d).

Plant heights were significantly different among genotypes and ranged from 57 cm or Minimum Length Grade 4+ (GL-2) to 121 cm or Minimum Length Grade 1 (GL-11; Table 1)[16], with the dwarf stature types being significantly shorter than the tall statue types. All adhered to the Stem Strength Grades 1–4 of 15° and fell within the Stem Deviation Curvature of Grade 1 < 5 cm[16]. The significantly tallest genotypes were GL-10 and GL-11 at 117.2 and 120 cm, respectively. Plant width ranged from 13 cm (GL-2, dwarf stature) to 60 cm (GL-9, tall stature; Table 1), although none were not significantly different. Likewise, the number of leaves was insignificant and unrelated to plant statue, despite ranging from 6 (GL-3, -4, -5) to 9 leaves (GL-2; Table 1).ong the numerous and divergent genotypes tested, the phenotypic traits of importance for cut flower use, only flowering week and plant height were significantly different; all other traits were insignificant (Table 1).

Postharvest experiment

Since the gladiolus inflorescence cut stem lengths and numbers of flower buds (florets) per inflorescence (Fig. 3) varied due to varying stem lengths among the dwarf vs tall statures (stem lengths had to be long enough to stand in the preservative solution), there were significant differences within and among treatments (DDW, FLFP) and among most genotypes (Table 2). The interaction of genotype × treatment was not significant. As expected, the shortest two sets of inflorescences in both treatments (DDW, FLFP) had significantly shorter cut stem lengths than all other genotypes, all of which were classified as tall stature types. The significantly tallest inflorescence cut stem lengths occurred in GL-3 for both treat-

Fig. 4 Stage when 50% of the gladiolus flowers/stem (occurring on genotype GL-8 on day 9) are commercially classified as 'wilted' or 'dead' [24]. Scale: bar = 3 cm.

ments and would be ranked as Grade 3 for Minimum Length (82 and 91.5 cm, FLFP and DDW, respectively; Table 2)[16]. Most of the other tall stature genotypes overlapped for inflorescence cut stem lengths. As would be expected, inflorescence cut stem lengths were significantly and positively correlated with all traits except for no. flowers senesced/day, Σ no. flowers senesced, final pH, and ΔpH (Table 3).

An example of the floret opening stage on Day 0, the start of the experiment are shown in Fig. 5. The mean Σ number of floret buds/stem varied significantly across genotypes but not treatments, ranging from 7.7 (GL-1, short stature) Grade 3 flower number/stem to 17.8 Grade 1 flower number/stem (GL-3, tall stature; Table 2)[16]. The interaction of genotype × treatment was not significant. This trait was positively and significantly correlated with Σ no. open flowers (r = 0.39), but negatively and significantly correlated with inflorescence internode length (r = −0.58), Σ % open flowers (r = −0.18) and no. saleable days (r = −0.34; Table 3).

The mean inflorescence internode length ranged from 3.9 cm (GL-2, FLFP treatment) to 7.5 cm ('Manhattan', DDW; Table 2). Genotypes and treatments were significant whereas the genotype x treatment interaction was not. This trait was significantly and positively correlated only with reproductive traits, i.e., Σ % open flowers, floret 1 diameter, floret 3 diameter (Table 3). Inflorescence internode length is not a function of, nor correlated with stature, as several significantly shorter internode lengths occurred in both the short and tall statures, whereas only the significantly longest internodes occurred in the tall stature genotypes (Table 2).

The Σ number and Σ percent of opened flowers/inflorescence at the end of the experiment, ranged from 2.8% and 22% (GL-5) to 12.8% (GL-11) and 94% (GL-10; Table 2), respectively. The significantly lowest percentages of opened flowers/inflorescence occurred in both short (GL-2, 28%) and taller stature (GL-5, 22%) genotypes. An example of the flower opening/closing on Day 9 is shown for a single stem (Fig. 6) versus all stems within a genotype (Fig. 7). In some instances, flowers never opened in both solution treatments (Fig. 8). Genotypes differed significantly although treatments did not but their interaction was significant (Table 2). Both traits were significantly and positively correlated with each other (r = 0.8) as well as each trait with floret 1 and 3 diameters, but negatively and significantly correlated with the number of saleable days (r = −0.62, r = −0.36, respectively; Table 3).

As would be expected, Day 0 stem FWs were not significantly different among treatments since the experiment had not yet commenced. However, genotypes were very highly significantly different, ranging from 9.9 g (GL-2, short stature) to 54.9 g (GL-3, tall stature; Table 4). The interaction of genotype × treatment was not significant. Day 0 FW were positively and significantly correlated with day 9 FW (r = 0.89) and DW (r = 0.91), inflorescence cut stem length (r = 0.81), Σ number of flower buds/stem (r = 0.68), Σ number of open flowers (r = 0.58), Σ % open flowers (r = 0.23), floret 1 diameter (r = 0.39), floret 3 diameter (r = 0.35), and solution volume/stem (r = 0.75; Table 3). Day 0 FW was significantly but negatively correlated with the number of saleable days (r = −0.33; Table 3); all other trait correlations were not significant.

Day 9 stem FWs were very highly significantly different for both genotypes and treatments, but not for their interaction (Table 4), ranging from 8.7 g (GL-2, DDW) to 54.5 g ('Beatrice', FLFP). This range was slightly lower than the range for Day 0, as illustrated by the ΔFW wherein most genotypes had negative ΔFW (−0.2 to −15.1). The exceptions occurred primarily in the FLFP treatment in both dwarf and tall stature genotypes; the only positive ΔFW in the DDW treatment was GL-5 (ΔFW = 1.3; Table 4). Day 9 FW were significantly and positively correlated with all traits except inflorescence internode length, Σ % open

Table 2. Mean inflorescence cut stem length (cm), total no. of floret buds/stem, inflorescence internode length (cm), total no. (%) opened flowers in dwarf and tall stature gladiolus genotypes tested with two treatment solutions applied as continuous vase solutions.

Genotype	Inflorescence cut stem length (cm)		Total no. floret buds/stem	Inflorescence internode length (cm)		Total no. (%) opened flowers
	DDW	FLFP	Pooled	DDW	FLFP	Pooled
Dwarf stature (< 90 cm)						
GL-1	43.5a	42.5a	7.7a	5.3ab	5.8a-c	5.1ab (66%)
GL-2[z]	40.2a	37.0a	9.5a-c	4.2a	3.9a	2.89a (28%)
Tall stature (> 90 cm)						
GL-3	91.5d	82.0d	17.8g	4.8a	5.0ab	12.2de (68%)
GL-4	57.4b	64.8bc	10.1a-d	5.8a-c	6.3bd	6.2a-c (62%)
GL-5[x]	65.8bc	56.8b	13.2e-f	4.5a	4.8a	2.8a (22%)
GL-6	65.3bc	71.7c	11.9c-f	5.8a-c	5.7a-c	6.9a-c (59%)
GL-7[w]	62.0b	73.3c	12.9d-f	4.9ab	5.6a-c	5.5ab (43%)
GL-8	69.8bc	68.3bc	10.2a-e	6.5cd	7.1d	9.0cd (88%)
GL-9[w]	60.0b	57.7b	9.0ab	6.9d	6.2bd	8.1b-d (90%)
GL-10[w]	67.0bc	69.0bc	10.6a-e	6.5cd	6.3bd	10.0c-e (94%)
GL-11[y]	76.0c	68.0bc	14.0f	5.4a-c	4.9ab	12.8e (91%)
'Beatrice'	73.5c	69.2bc	12.3c-f	5.9a-c	5.7a-c	7.2bc (58%)
'Manhattan'	61.8b	67.0bc	8.3ab	7.5d	8.4d	7.6bc (92%)
Significance[v]						
Genotype (G)	F = 17.31***		F = 13.26***	F = 8.29***		F = 6.48***
Treatment (T)	F = 13.12***		F = 0.63ns	F = 3.76*		F = 1.33ns
G × T	F = 1.38ns		F = 0.66ns	F = 0.64ns		F = 1.88*

DDW = deionized, distilled water; FLFP = Floral Life floral preservative or Pooled if treatments were not significantly different. There were n = 6 replications/treatment solution/genotype unless noted otherwise; mean separations within columns based on Tukey's Honestly Significantly Difference (HSD) test at $\alpha = 0.05$.

Table 3. Correlation matrix for the postharvest cut flower traits examined in dwarf and tall stature gladiolus genotypes tested with two treatment solutions applied as continuous vase solutions.

	Day 0 FW	Day 9 FW	ΔFW	Day 9 DW	% water	Inflor. cut stem length	Σ no. flw buds/stem	Inflor. internode length	Σ no. open flws	Σ % open flws	Floret 1 dia.	Floret 3 dia.	No. flws senesced /day	Σ no. flws senesced	No. saleable days	Final pH	ΔpH	Sol'n vol/stem
Day 0 FW	1.0																	
Day 9 FW	0.89**	1.0																
ΔFW	−0.21*	0.24**	1.0															
Day 9 DW	0.91**	0.88**	0.09	1.0														
% water	−0.01	0.18*	0.26**	−0.25**	1.0													
Inflor. cut stem length	0.81**	0.8**	0.06	0.78**	0.03	1.0												
Σ no. flw buds/stem	0.68**	0.64**	−0.07	0.49**	0.24**	0.64**	1.0											
Inflor. internode length	−0.05	0.03	0.16	0.16	−0.24**	0.21*	−0.58**	1.0										
Σ no. open flws	0.58**	0.31**	−0.43**	0.45**	−0.34**	0.53**	0.39**	0.05	1.0									
Σ % open flws	0.23*	−0.01	−0.39**	0.21*	−0.51**	0.27*	−0.18*	0.46**	0.80**	1.0								
Floret 1 dia.	0.39**	0.37**	0.12	0.49**	−0.18	0.36**	0.01	0.36**	0.31**	0.32**	1.0							
Floret 3 dia.	0.35**	0.34**	0.07	0.47**	−0.18	0.39**	0.01	0.37**	0.34**	0.33**	0.88**	1.0						
No. flws senesced/day	−0.07	−0.11	−0.03	−0.04	−0.11	−0.01	−0.01	0.01	0.09	0.06	0.02	0.01	1.0					
Σ no. flws senesced	−0.03	−0.08	−0.01	0.01	−0.14	−0.01	0.02	−0.02	0.03	0.00	−0.01	−0.02	0.94**	1.0				
No. saleable days	−0.33**	−0.02	0.46**	−0.20*	0.29**	−0.25**	−0.34**	0.17	−0.62**	−0.36**	−0.19*	−0.25**	0.01	0.03	1.0			
Final pH	0.21	−0.02	−0.53**	0.08	−0.19	0.09	0.07	0.03	0.16	0.13	0.15	−0.05	0.02	0.04	−0.08	1.0		
Δ pH	−0.27	−0.17	0.21	−0.26	0.12	−0.01	0.03	−0.03	−0.13	−0.13	−0.11	−0.33	0.01	−0.01	0.01	0.13	1.0	
Sol'n vol/stem	0.75**	0.79**	−0.22	0.86**	−0.09	0.76**	0.46	0.38	0.33	0.24	0.35	0.15	−0.19	−0.23	0.10	0.22	0.19	1.0

DDW = deionized, distilled water; FLFP = Floral Life floral preservative or Pooled if treatments were not significantly different.

flowers, number of flowers senesced/day, Σ number of flowers senesced, final pH, and Δ pH (Table 3).

The percent water ranged from 66.7% (GL-9, DDW) to 90.9% (GL-5, FLFP; Table 4), based on fresh weight – dry weight differences. The lowest percent water occurred in tall stature genotypes instead of the dwarf genotypes. The lowered level of water in some genotypes, e.g. GL-9 might indicate increased levels of fibers in the stem stalks and/or leaves but would need to be studied further to identify the root cause of depressed percent water.

The 1st flower (floret) diameters were very highly significant for genotypes and treatments but only highly significantly different for their interaction (genotype x treatment; Table 5). The mean range of flower diameters for the 1st flower was 4.1–7.8 cm for DDW (miniature) and 4.6–8.1 cm for FLFP treatments (miniature). While most means overlapped in significance, there were genotypes with the significantly smallest (GL-6) and largest 1st flower diameters (GL-7 to GL-11, 'Beatrice' and 'Manhattan') in the DDW treatment (Table 5). Comparatively, the FLFP treatment smallest 1st flower diameters were GL-4 and GL-6, as opposed to the significantly largest diameters occurring in GL-3, GL-8 to GL-11, 'Beatrice' and 'Manhattan'. Thus, GL-6 consistently had the smallest 1st flower diameter in both treatments, whereas GL8 to GL-11, 'Beatrice', and 'Manhattan' consistently had the significantly largest 1st flower diameters (Table 5). The 1st flower diameter was significantly and positively correlated with all other traits except for ΔFW, % water, Σ number of flower buds/stem, number of flowers senesced/day, Σ number of flowers senesced, final pH, ΔpH, and solution vol./stem (Table 3).

Similar to the 1st flower diameters, the 3rd flower diameters were also very highly significant for genotypes and treatments but only highly significantly different for their interaction (genotype × treatment; Table 5). The mean range of flower diameters for the 3rd flower in the DDW treatment was 3.9 cm (GL-6; miniature) to 6.8 cm (GL-8; small) and 4.1 (GL-6; miniature) to 7.8 cm ('Beatrice'; miniature) in the FLFP. Similar to 1st flowers, GL-6 also displays genetic stability across treatments for the smallest 3rd flower diameters (Table 5).

Final pH of the vase solution treatments was not significantly different among genotypes or genotype x treatment interaction but was very highly significantly different for treatment (Table 5). While the beginning pH of the water was pH = 8.38, prior to adding floral preservative to FLFP, as soon as it was added the FLFP starting pH decreased to pH = 4.07. With the exception of ΔFW (r = −0.53), all final pH correlations with other traits were nonsignificant and nearly zero (Table 3).

Final pH values for the DDW treatment reduced significantly from the beginning (pH = 8.38) with a pooled mean of pH = 4.92 and ranging from pH = 4.2 (GL-5) to pH = 7.8 ('Beatrice') across genotypes although the means were not significantly different (Table 5). In most cases of DDW where the final pH

Fig. 5 Example cut gladiolus stems (stage 2) at day 0, the beginning of the experiment, for all six replications of one genotype. Scale: bar = 3 cm.

was the highest, the inflorescence cut stem lengths were significantly longer and total number of floret buds/stem were significantly higher (Table 2). Thus, the inflorescence cut stem length and/or total number of floret buds/stem may be inferred to require additional solution changes during the test period to eliminate potentially higher levels of phloem unloading. Pooled mean final pH values for the FLFP treatment was pH = 4.24, significantly lower than that of DDW (Table 5). Specific genotype pH ranged from pH = 3.5 (GL-1) to pH = 4.8 (GL-7), although they did not differ significantly.

Solution volume used / stem (uptake) were not significantly different for genotypes or genotype × treatment interactions but significantly different for treatments (Table 5). Pooled genotypic means were 24.7 ml (DDW), with significantly more

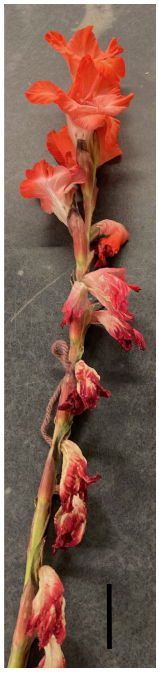

Fig. 6 Gladiolus stem post-stage when > 50% of the gladiolus flowers have wilted (GL-11 rep 1 on day 9). Scale: bar = 3 cm.

Fig. 7 Set of six replicate gladiolus stems (GL-6 stems all reps) at the end of the experiment on day 9. Scale: bar = 3 cm.

solution volume used / stem than FLFP (23.9 ml) although they overlapped (Table 5). Four traits had positively and highly significant correlations with solution volume used / stem: day 0 FW (r = 0.75), day 9 FW (r = 0.79), day 9 DW (r = 0.86), and inflorescence cut stem length (r = 0.76; Table 3); all other traits were not correlated.

The ANOVAs for mean number of flowers senesced/day (days 1–9) and Σ number of flowers senesced (days 1-9) showed significance for genotypes, but not for treatments or their interactions (Table 6). The mean number of flowers senesced/day ranged from 0.1 (GL-5, GL-7) to 0.6 (GL-8; Table 6). GL-2, -3, -5, -7, and -11 all had significantly less flowers senesced/day than GL-4, -8, and 'Manhattan'; the remaining genotypes all overlapped. For the Σ number of flowers senesced (days 1-9), mean values ranged from 0.85 (GL-5) to 6.8 (GL-8; Table 3). GL-2, -5, -11, and 'Beatrice' had significantly lower number of flowers senesced over the 9-day period than GL-4, -8, and 'Manhattan' (Table 3). Lower numbers of senescing flowers/day or in total would be ideal traits to breed and select for to enhance postharvest longevity, instead of higher numbers (faster senes-

Fig. 8 Example of gladiolus flowers failing to open completely (GL-6 rep 2 stem on day 9). Note: This genotype often produced a secondary flowering shoot (left). Scale: bar = 3 cm.

Table 4. Mean day 0 stem fresh weight (FW; g), day 9 stem FW (g), ΔFW (g; day 9 FW – day 0 FW), day 9 dry weight (DW; g), % water in dwarf and tall stature gladiolus genotypes tested with two treatments applied as continuous vase solutions.

Genotype	Day 0 stem FW (g)	Day 9 stem FW (g)		ΔFW (g)		Day 9 DW (g)		% Water	
	Pooled	DDW	FLFP	DDW	FLFP	DDW	FLFP	DDW	FLFP
Dwarf stature (< 90 cm)									
GL-1	15.8ab	13.9ab	14.6ab	−2.8a-d	−0.2b-d	1.9a	2.0a	75.8b	75.4b
GL-2[z]	9.9a	8.7a	9.9a	−3.2a-d	1.8cd	1.2a	0.9a	75.2b	82.2bc
Tall stature (> 90 cm)									
GL-3[y]	54.9g	47.7g	50.1	−15.1a	3.0cd	5.0e-g	5.5fg	80.9bc	80.2bc
GL-4	21.9a-c	17.7a-c	27.3b-e	−1.6b-d	2.8cd	2.5ab	3.4a-d	75.6b	77.8bc
GL-5[x]	24.3a-d	30.1c-e	25.6b-e	1.3cd	5.6d	2.3ab	1.2a	85.8c	90.9cd
GL-6	38.4d-f	30.6c-e	46.9g	−5.9ab	6.7d	3.7b-e	4.5c-g	78.6bc	82.4bc
GL-7[w]	44.4e-g	37.4d-f	53.6g	−6.2a	8.2d	5.1e-g	5.9g	76.0bc	80.2bc
GL-8	22.2a-c	29.4b-e	42.2e-g	−12.4a	9.5d	4.4c-g	5.1e-g	74.1b	78.7c
GL-9[w]	27.4b-d	16.3a-c	19.1a-c	−11.4a	−7.9a	3.2a-d	3.8b-e	66.7a	67.2a
GL-10[w]	29.6b-e	24.1a-d	31.1c-e	−1.6b-d	−2.2b-d	3.3a-d	4.2b-g	76.1bc	76.0bc
GL-11[y]	34.2c-f	27.2b-e	31.4c-e	−6.6a	3.8cd	4.3c-g	3.7b-e	72.8ab	71.1ab
'Beatrice'	46.9fg	42.5e-g	54.5g	−2.2a-d	5.3d	5.1e-g	5.8g	78.7c	80.7bc
'Manhattan'	30.8b-e	25.4b-e	31.3c-e	−3.2a-d	−1.6b-d	3.1a-d	3.7b-e	78.0c	78.6c
Significance[v]									
Genotype (G)	F = 15.54***	F = 20.99***		F = 5.45***		F = 14.39***		F = 21.80***	
Treatment (T)	F = 0.52ns	F = 22.42***		F = 125.45***		F = 43.82***		F = 19.69***	
G × T	F = 1.45ns	F = 1.48ns		F = 4.99***		F = 1.47ns		F = 1.54ns	

DDW = deionized, distilled water; FLFP = Floral Life floral preservative or Pooled if treatments were not significantly different.
There were n = 6 replications/treatment solution/genotype unless noted otherwise; mean separations within columns based on Tukey's Honestly Significantly Difference (HSD) test at $\alpha = 0.05$.

Table 5. Mean 1st flower diameter (cm), 3rd flower diameter (cm), final pH, ΔpH, solution volume used per stem (ml) in dwarf and tall stature gladiolus genotypes tested with two treatment solutions applied as continuous vase solutions.

Genotype	1st Flower diameter (cm)		3rd Flower diameter (cm)		Final pH (ΔpH)		Sol'n vol./stem (ml)	
	DDW	FLFP	DDW	FLFP	DDW	FLFP	DDW	FLFP
Dwarf stature (< 90 cm)								
GL-1	5.5a-d	6.5d-g	4.8a	5.4a-d	4.9 (3.4)	3.5 (0.6)	1.7	3.3
GL-2[z]	5.0a-d	5.0a-d	4.2a	6.2b-e	4.9 (3.4)	4.2 (−0.09)	5	3.2
Tall stature (> 90 cm)								
GL-3[y]	7.5g	7.2fg	6.2b-e	5.6a-d	4.9 (3.5)	4.2 (−0.1)	35	35
GL-4	5.0a-d	4.8ab	5.1a-c	4.7a	5.3 (3.1)	4.1 (−0.04)	16.8	16.7
GL-5[x]	5.8b-e	6.0c-f	5.2a-c	5.3a-d	4.2 (4.2)	4.1 (−0.02)	28	20
GL-6	4.1a	4.6ab	3.9a	4.1a	4.9 (3.5)	4.2 (−0.1)	21.7	21.7
GL-7[w]	7.5g	5.0a-d	5.5a-d	5.5a-d	4.9 (3.4)	4.8 (−0.7)	20	30
GL-8	7.5g	7.2fg	6.8de	6.3b-e	5.1 (3.3)	4.1 (−0.1)	30	25
GL-9[w]	7.8g	6.8e-g	6.3b-e	5.8a-d	5.1 (3.3)	4.2 (−0.1)	6.7	5
GL-10[w]	7.2fg	7.7g	6.1b-e	7.3e	5.0 (3.4)	4.2 (−0.1)	6.7	10.3
GL-11[y]	7.0fg	6.5d-g	6.2b-e	6.0b-e	5.2 (3.2)	4.1 (−0.05)	30	30
'Beatrice'	6.8e-g	7.8g	6.1b-e	7.8e	4.4 (3.9)	4.5 (−0.4)	60	50.8
'Manhattan'	7.0fg	8.1g	6.0b-e	7.0e	5.2 (3.2)	4.1 (−0.05)	60	60
Genotypes Pooled					**4.92 (3.45)b**	**4.24 (−0.1)a**	**24.7ab**	**23.9a**
Significance[v]								
Genotype (G)	F = 15.51***		F = 8.19***		F = 0.22ns		F = 1.10ns	
Treatment (T)	F = 20.59***		F = 14.66***		F = 13.87***		F = 1.91*	
G × T	F = 2.27**		F = 2.51**		F = 0.91ns		F = 0.96ns	

[z] n = 4 reps. [y] n = 2 reps. [x] n = 5 reps. [w] n = 3 reps. [v] *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns not significant.
DDW = deionized, distilled water; FLFP = Floral Life floral preservative or Pooled if treatments were not significantly different.
There were n = 6 replications/treatment solution/genotype unless noted otherwise; mean separations within columns based on Tukey's Honestly Significantly Difference (HSD) test at $\alpha = 0.05$.

cence). Neither trait was not significantly correlated with any other trait excepting each other (r = 0.94; Table 3). All Chi-square (χ^2) tests for equal distribution (1:1:1:1:1:1:1:1:1:1; df = 8; χ^2 = 15.507) of the mean number of flowers senesced/day/genotype in days 1–9 and the total number of flowers sensed over the postharvest experiment period (days 1–9) in dwarf and tall stature gladiolus genotypes were not significant (Table 7), indicating that the rate of flower senescing per day or in total was the same (linear), regardless of genotype.

The number of saleable days (when the 5th floret from the base wilted) in dwarf and tall stature gladiolus genotypes tested with two treatment solutions ranged from 3 d (GL-11) to

8 d (GL-1, 'Manhattan') for DDW and 4.5 d (GL-11) to 8 d (GL-1, -2, -5, -6, -7, 'Beatrice') for FLFP vase treatment solutions (Table 6). The lowest number of saleable days were significantly lower than the highest values found, indicating significant genetic differences among the germplasm tested with particularly different results among the two comparison cultivars. The number of saleable days was negatively but significantly correlated with eight traits (day 0 FW, day 9 DW, inflorescence cut stem length, Σ number of flower buds/stem, Σ number of open flowers, Σ % open flowers, floret 1 diameter, floret 3 diameter) or positively and significantly correlated with two traits (ΔFW, % water; Table 3). These negative or positive significant correlations will be important to direct future breeding efforts and select for enhanced postharvest life.

Discussion

Field production experiments

VBD occurred within a tight 3-week window among all genotypes, regardless of stem height (Table 1). When categorizing flowering time by the North American Gladiolus Council classifications, GL-4, -5, -8, -9, and 'Manhattan' are midseason (84 d); GL-1, -3, -6, -7, -10, -11, and 'Beatrice' are late (91-99 d) flowering; GL-2 is very late (> 100 d)[11]. While early types exist in the breeding program, by chance they were not selected for this study. Future research into earlier VBD types might reveal faster leaf unfolding rates; potential genotypes to research would be our cycle 1 RGC which flower in the first year in < 1 yr from seed[8,26,27]. Classification of genotypes by flowering date ranged from late (14 wks or 98 d) to very late (19 wks or 133 d; Table 1)[9,10].

The significant differences in plant height were such that the tested genotypes were categorized from Grades 1-4 for Minimum Length Grade to 117.2 (GL-10) - 121 cm (GL-11; Table 1)[16]. Since taller genotypes exist, both in the UMN breeding program (137 cm is the tallest found; Anderson, 2021, unpublished data) and elsewhere (183 cm)[33], the significance of plant height differences could be further accentuated, although stems taller than GL-10 and -11 (Grade 1) would exceed the grading standards.

Among the numerous and divergent genotypes tested for phenotypic traits of importance for cut flower use, only flowering week and plant height were significantly different; all other traits were not significant (Table 1). If this germplasm sampling is an accurate reflection of gladiolus cut flower genotypes, then future breeding and selection efforts should be focused on these two traits without regards to the others (no. weeks to VBD, flowering termination week number, plant width, no. leaves).

Table 6. Mean number of flowers senesced/day in days 1–9, total number of flowers sensed in days 1-9, and number of saleable days (when the 5th floret from the base wilted) in dwarf and tall stature gladiolus genotypes tested with two treatment solutions applied as continuous vase solutions.

Genotype	No. of flowers senesced/day (days 1–9)	Total no. of flowers senesced in days 1–9	No. of saleable days	
	Pooled	Pooled	DDW	FLFP
Dwarf stature (<90 cm)				
GL-1	0.35ab	3.05ab	8.0e	8.0e
GL-2[z]	0.15a	1.10a	7.5b-e	8.0e
Tall stature (>90 cm)				
GL-3[y]	0.25a	2.25ab	5.5a	7.0b-e
GL-4	0.50b	4.65b	7.7c-e	7.5b-e
GL-5[x]	0.10a	0.85a	7.0b-e	8.0e
GL-6	0.45ab	3.85ab	7.8c-e	8.0e
GL-7[w]	0.10a	1.10a	6.0a	8.0e
GL-8	0.60b	6.80b	6.7bc	7.8c-e
GL-9[w]	0.35ab	3.15ab	7.0b-e	6.0a
GL-10[w]	0.40ab	3.2ab	6.7bc	6.7bc
GL-11[y]	0.25a	2.25a	3.0a	4.5a
'Beatrice'	0.35ab	2.95a	7.8c-e	8.0e
'Manhattan'	0.50b	4.5b	8.0e	7.3b-e
Significance[v]				
Genotype (G)	F = 2.446**	F = 1.98*	F = 9.98***	
Treatment (T)	F = 0.55ns	F = 0.69ns	F = 4.47**	
G × T	F = 0.69ns	F = 0.73ns	F = 1.69*	

[z] n = 4 reps. [y] n = 2 reps. [x] n = 5 reps. [w] n = 3 reps. [v] *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, ns not significant.
DDW = deionized, distilled water; FLFP = Floral Life floral preservative or Pooled if treatments were not significantly different.
There were n = 6 replications/treatment solution/genotype unless noted otherwise; mean separations within columns based on Tukey's Honestly Significantly Difference (HSD) test at $\alpha = 0.05$.

Postharvest experiment

Short- and tall-stature genotypes differed significantly for inflorescence cut stem length, matching plant height findings which infers that most of the plant height is influenced by the inflorescence length, rather than leaf internode lengths. Plant height would not need further analyses, rather only measurements of inflorescence cut stem lengths. Since inflorescence cut stem lengths were significantly and positively correlated with most traits (Day 0, 9 FW, Day 9 DW, Σ no. flower. buds/stem, inflorescence internode length, Σ no. or % open flowers, 1st and 3rd flower diameter, solution volume/stem), they may be linked traits to aid in co-selection all traits. Future research will determine whether the traits share similar single nucleotide polymorphisms (SNPs) or map to a single chromosome which would aid in marker-assisted selection.

Since the Σ number of floret buds/stem varied significantly among genotypes, it could be a heritable trait for increased production capacity/stem. This trait hasn't been examined in previous postharvest studies[19,24,32], but is a critical trait of floriferousness that gladiolus breeding programs would want to breed and select for increased 'flower power'[34].

Unlike what might be expected, inflorescence internode length is not correlated with stature (Table 3), since several significantly shorter internode lengths occurred in both the short and tall statures. However, only the significantly longest internodes occurred in the tall stature genotypes (Table 2) which may mean a threshold internode length has to be reached before this is correlated with plant stature. The ideal internode length could vary, depending on the flower size (miniature or < 6.3 cm to giant > 14 cm) and flower number, as long as stem strength is adequate[35].

The Σ number and Σ percent of opened flowers/inflorescence of 2.8 (22%; GL-5) to 12.8 (GL-11) and 94% (GL-10; Table 2), respectively, exceeded the range of previous reports[19]. In some cases, the lower values were due to flowers which would not open (Fig. 8), regardless of solution treatment. Previous research found varying opened flowers/inflorescence in 'White Prosperity' (36.3%–84.1%) under various treatment solutions in

Table 7. Frequencies and Chi-square (χ^2) tests for equal distribution (1:1:1:1:1:1:1:1:1; df = 8; χ^2 = 15.507) of the mean number of flowers senesced/day/genotype in days 1–9 and the total number of flowers sensed over the postharvest experiment period (days 1–9) in dwarf and tall stature gladiolus genotypes tested with two treatment solutions applied as continuous vase solutions.

Genotype	Treatment	Mean no. of flowers senesced/day/genotype									χ^2 (sig.)
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	
Dwarf stature (< 90 cm)											
GL-1	DDW	0.00	0.00	0.00	0.67	0.17	0.67	0.50	0.83	0.3	3.82ns[z]
	FLFP	0.00	0.00	0.00	1.00	0.17	0.50	0.67	1.00	0.4	3.07ns
GL-2	DDW	0.00	0.17	0.00	0.33	0.17	0.33	0.17	0.33	0.2	5.92ns
	FLFP	0.00	0.17	0.00	0.17	0.00	0.17	0.00	0.17	0.1	7.51ns
Tall stature (> 90 cm)											
GL-3	DDW	0.00	0.17	0.50	0.50	0.33	0.33	0.17	0.33	0.30	4.51ns
	FLFP	0.17	0.33	0.17	0.33	0.33	0.33	0.17	0.33	0.20	4.90ns
GL-4	DDW	0.00	0.00	0.67	0.83	1.00	0.83	0.50	1.00	0.50	1.50ns
	FLFP	0.00	0.17	0.50	0.67	0.67	0.83	0.67	1.00	0.50	1.77ns
GL-5	DDW	0.00	0.00	0.17	0.17	0.17	0.17	0.17	0.17	0.10	6.90ns
	FLFP	0.00	0.00	0.00	0.17	0.00	0.17	0.17	0.17	0.10	7.51ns
GL-6	DDW	0.00	0.00	0.83	0.33	0.83	0.83	0.67	1.00	0.50	1.79ns
	FLFP	0.00	0.00	0.50	0.33	0.67	0.50	0.50	0.67	0.40	3.28ns
GL-7	DDW	0.17	0.17	0.33	0.33	0.33	0.33	0.33	0.17	0.20	4.90ns
	FLFP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.00ns
GL-8	DDW	0.83	0.50	0.83	0.67	1.00	0.50	1.00	1.00	0.70	0.43ns
	FLFP	0.17	0.50	0.50	0.50	1.00	0.50	0.50	0.50	0.50	2.08ns
GL-9	DDW	0.00	0.50	0.17	0.50	0.50	0.33	0.50	0.50	0.30	3.61ns
	FLFP	0.33	0.50	0.33	0.50	0.33	0.50	0.33	0.50	0.40	3.10ns
GL-10	DDW	0.00	0.17	0.50	0.50	0.50	0.50	0.50	0.50	0.40	3.28ns
	FLFP	0.00	0.17	0.50	0.50	0.50	0.50	0.50	0.50	0.40	3.28ns
GL-11	DDW	0.00	0.33	0.17	0.17	0.17	0.17	0.17	0.17	0.20	6.17ns
	FLFP	0.33	0.50	0.33	0.33	0.33	0.33	0.33	0.33	0.30	3.85ns
'Beatrice'	DDW	0.00	0.00	0.17	0.50	0.83	0.50	0.50	0.67	0.40	3.28ns
	FLFP	0.00	0.00	0.00	1.00	0.17	0.17	0.00	1.33	0.30	4.04ns
'Manhattan'	DDW	0.00	0.00	0.67	0.50	0.83	0.17	0.83	0.83	0.40	2.53ns
	FLFP	0.00	0.17	0.67	0.67	0.83	0.83	1.00	1.00	0.60	1.16ns

[z] ns not significantly different from the null hypothesis that the number of flowers senesced/day do not differ.
DDW = deionized, distilled water; FLFP = Floral Life floral preservative.

two experiments[19], while other studies did not record this trait[24,32]. Both traits are important to assess salability and flower power for cut flower usage.

Previous research did not find significant genotypic differences for FWs among 'American Beauty' and 'Snow Princess'[24], although this lack of significant FWs may be due to either the low number of genotypes tested or similar responses among the two cultivars. Thus, the increased number of genotypes in the present study have greater genetic diversity and provide new insights into FW levels. Day 0 stem FWs of both dwarf stature genotypes (GL-1, GL-2) overlapped with several tall stature types (GL-4, GL-5, and GL-8), which was unexpected.

Day 9 stem FWs differed significantly among genotypes and treatments (Table 4) with a wide range in expression (8.7 g, GL-2, DDW to 54.5 g, 'Beatrice', FLFP). In previous research, FWs and ΔFW changed significantly within 'White Prosperity', based on post-harvest solution treatments, although all ΔFW were positive in most of the silver-based treatments except for tap water, 0.01, and 0.1 mg·L^{-1} nano-silver continuous vase solutions[19].

The 1st flower diameters classified the many of the genotypes as miniature[10,11,16,35]. GL-6 consistently had the smallest 1st flower diameter in both treatments, whereas GL-8 and GL-11, 'Beatrice', and 'Manhattan' respectively, consistently had the significantly largest 1st flower diameters (Table 5). For all genotypes tested, the 1st flower diameters were smaller than those previously reported for 'American Beauty' (11.18 cm; small) and 'Snow Princess' (11.16 cm; small)[11,24] but similar in dimensions to 'White Prosperity' (6.5–9.1 cm; miniature to small)[11,19]. These differences could be either genetic, environmental or physiological with less reserved carbohydrates available for the 1st or basal floret[36]. Genotypic stability for the 1st flower diameter exhibited by the tested genotypes make them valuable germplasm for breeding purposes.

The 3rd flower diameters of 3.9 cm (GL-6; miniature) in the DDW treatment, to 7.8 cm ('Beatrice'; miniature) in FLFP, were all smaller floral diameters than reported for 'American Beauty' (9.98 cm; small) and 'Snow Princess' (9.74 cm; small)[11,16]. GL-6 also displays genetic stability across treatments for the smallest 3rd flower diameters, regardless of solution treatment (Table 5). This genetic stability, regardless of preservative solutions is of value for future breeding efforts.

As would be expected, final pH differed by treatment solutions. The final pH values were consistently lowest in all genotypes treated with FLPP (Table 5), as would be expected with floral preservatives[11,19,24,32,35]. It would be important to maintain current recommendations of floral preservatives to maximize gladiolus postharvest life by ensuring the solution pH most closely matches that of cell pH.

While previous studies have not reported measuring ending pH for treatments or gladioli genotypes, our data provide an insight into the ability of cut gladiolus to decrease solution pH

without added floral preservatives. These findings were completely unexpected and show the resilience of cut gladiolus as a cut flower crop for floral designs[2]. The implications of inflorescence cut stem lengths and total number of floret buds/stem on final pH are important considerations for future breeding and selection of the cut flower crop.

Solution treatments had little to no effect on solution volume used per stem, despite having floral preservatives recommended to increase gladiolus vase life[21]. The highest solution volume used per stem of 60 ml ('Beatrice', 'Manhattan') matched similar levels for 'Friendship' over the same treatment period of 9 d[32]. Solution uptake volumes for other genotypes were lower than that of 'Friendship'. 'American Beauty' and 'Snow Princess' had slightly higher levels of solution volume used per stem (71.68–77.28 ml) over a 12-d period than our results[24].

The range of saleable days was surprisingly similar despite not having floral preservative in one of the treatments (DDW). However, since the consumer vase life expectancy is 6–10 d[21], any genotypes with < 6 d vase life would not be recommended as cut gladioli.

The similar rate of flower senescing per day or in total was the same (linear) and independent of genotype. This demonstrates consistent flower aging, regardless of vase solutions, across the postharvest test environment which will benefit the grower, distributor, wholesaler, retailer as well as the consumer. To the best of our knowledge, the heritability of these traits are unknown.

Conclusions

Since genotype effects were significant for all traits examined except for final pH and solution volume/stem (Table 2), a wide range of genetic variation exists across the dwarf vs. tall stature types for the remaining traits tested, indicating potential for continued breeding, selection, and improvement of cut flower gladiolus for the floricultural industry. Genotypes were either midseason, late or very late in flowering time; it had been expected that the dwarf or short stature types would have been earlier flowering. The lack of early flowering in these types may be due to slowed leaf unfolding or floral scape development despite the significantly shorter stem lengths; future research could clarify these developmental rates to be equalized across stem length (plant and inflorescence height). Surprisingly, GL-11 was taller than the two cultivars and classified as Minimum Length Grade 1. Leaf number variation (ranging from 6 to 9) was unexpected and may have genetic heritability which would impact selection for earlier flowering due to increased leaf unfolding time in those genotypes with higher leaf numbers. Floral preservative versus the control (no floral preservative) had significant effects on all traits except for total number of floret buds/stem, total number (%) of opened flowers, day 0 stem FW, number of flowers senesced / day (days 1–9), and total number of flowers senesced in days 1–9. Thus, the recommended incorporation of floral preservative to maximize floret opening, life (d), and overall performance warrants its continued use with this crop, although our study suggests that, for some genotypes, changing the vase solution > 1x/week would be warranted. However, the decrease in solution pH for the DDW treatment was unexpected and warrants further study on the content of phloem unloading in cut gladiolus. Heritability of all traits included herein should be studied in programmed crosses, coupled with molecular marker creation to aid in selection. To the best of our knowledge, only cold tolerance heritability has been studied in gladiolus[8]. While several genes have been identified at the molecular level, e.g. *UPSTREAM OF FLOWERING LOCUS C* (*UFC*) and *FLOWERING LOCUS C EXPRESSOR* (*FLX*)[25], the gibberellin receptor gene[37], and two ubiquitin promoters (*GUBQ2, GUBQ4*)[38], the gladiolus genome has yet to be sequenced, GWAS and marker-assisted selection have yet to be created and implemented to complement classic gladiolus breeding programs. Data from this study and others will be used to formulate a new cut flower gladiolus crop ideotype to direct breeding and selection efforts for public- and private-sector gladiolus breeding programs, similar to other cut flower floricultural crops such as perennial flax[39,40] and chrysanthemum[41].

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Conflict of interest

The author declares that there is no conflict of interest.

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