The Effect of Oasis® Floral Foam on the Postharvest Performance of Perennial Flax Cut Flowers

Julia Stuenkel[1], Neil O. Anderson[1], and Elizabeth Goodman[1]

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Abstract. **Perennial flax (*Linum* spp.) is a new crop under domestication at the University of Minnesota. It is being bred simultaneously for herbaceous perennial and cut flower production, as well as fiber, oil seed, and pollinator (ecosystem) services. Perennial flax is prized for its blue flowers, which are a rarity in the floriculture industry. Superior genotypes have been selected with high levels of postharvest vase life for use as a "filler" cut flower in floral designing. For flax to be a new specialty cut flower crop in floral designs, it must be amenable for use in floral foam, a classic "mechanic" used to hold flowers in place. However, the thin stems predicate careful insertion into design mechanics to avoid breakage. The research objective of this study was to determine single-stem insertion effects (stem bending) for three stem lengths (10, 16.25, and 22.5 cm) in Oasis® floral foam and testing two preservative solutions (±FloraLife®). Genotypes and solution types were significant on most measured factors but stem length was an insignificant effect for most genotypes and treatments. Despite perennial flax's thinner stems, as a filler flower, it can be used in standard floral foam which is the most commonly used mechanic in floral designs. Three genotypes (CF10, CF3, and CF5) had the best postharvest life, which can serve as the basis for future plant breeding efforts to maximize postharvest longevity of this new cut flower crop.**

Perennial flax (primarily *Linum austriacum* L., *Linum lewisii* Pursh, *Linum perenne* L.) is being bred and developed as a perennial alternative to the summer annual flax (*Linum usitatissimum* L.) for new uses beyond oilseed and fiber (Tork et al. 2019). Perennial flax serves many ecological services including as a cover crop and resource for pollinators in addition to being potential horticultural (cut flower, herbaceous perennial) and agronomic (oilseed, fiber) crops (Tork et al. 2023). All horticultural and agronomic crop ideotypes are being bred simultaneously (Anderson et al. 2023). Most perennial flax species have unique blue flowers, a rarity in cut flowers and floriculture (California Cut Flower Commission 2016). Research in perennial flax as a potential cut flower has shown an average vase life of either 7 to 9 d (Goodman et al. 2023; Goodman EA, Anderson NO, Tong CBS, unpublished data) or >9 d, with *L. perenne* and *L. austriacum* having the longest vase life (Tork et al. 2022).

The cut flower industry is a multimillion dollar industry (US Department of Agriculture, National Agricultural Statistics Service 2021). It is important to research the postharvest care and handling of new crops throughout the horticultural distribution chain, especially vase life, for consumers to get high-quality and long-lasting products (Anderson 2006; Teixeira da Silva 2006). Various cut flower genera have been found to respond differently to types of holding mixtures and hydrating solutions (Clark et al. 2010; Dole et al. 2009; Hunter 2013). Different postharvest holding periods and temperatures can also have significant effects on vase life, as well as leaf and flower chlorosis in specialty cut flowers such as *Daucus carota* (Kargakou and Darras 2022). Commercial preservative solutions are easily accessible to consumers and are consistently found to lengthen the vase life for cut flowers (Ahmad et al. 2016; Tork et al. 2022).

Anchorage of flower and foliage stems is critical to keep the materials in place in floral design artistry as well as maintain turgor pressure in the stems, leaves, and flowers by supplying water and floral preservatives to the cut stems for uptake by the xylem. While numerous types of materials can be used (e.g., rockwool, coir, Oshun Pouch™), floral foam is the most widely used mechanic worldwide to anchor flowers and foliage in floral designs (Diehl Scace and DelPrince 2023; Hunter 2013). Thus, it is important to determine how perennial flax stems respond to floral foam and their postharvest life before the crop can be commercialized as a specialty cut flower. Floral foam with only water has been found to lower the vase life of cut flowers including *Rosa ×hybrida* and *Campanula* spp. (Ahmad et al. 2014; Bosma and Dole 2002; Trevenzoli Favero et al. 2017); however, adding commercial preservative solutions for uptake by floral foam extends the vase life of hybrid roses (Ahmad et al. 2014). Unfortunately, hydrophilic floral foams, such as Oasis®, are made from nonrenewable resources and cannot be recycled or reused (Dirlam et al. 2019; Goldfeld 2023); however, a new industry is being created to supply a renewable foam. A compostable polylactide (PLA) floral foam is in testing and production (Goldfeld 2023, 2024), although sufficient commercial samples are not yet available for testing.

The objective of this study was to test select cut flower (CF) perennial flax genotypes from the University of Minnesota (UMN) breeding program for their use in Oasis® commercial floral foam. Tested genotypes have been studied to determine their postharvest longevity (Goodman et al. 2023; Tork et al. 2022; Goodman EA, Anderson NO, Tong CBS, unpublished data). The following null hypothesis was

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[1]Department of Horticultural Science, University of Minnesota, 1970 Folwell Avenue, St. Paul, MN 55108, USA

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N.O.A. is the corresponding author. E-mail: ander044@umn.edu.

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tested: H_o: There is no significant difference of stem length or floral preservative solution on the vase life longevity among the 15 CF perennial flax genotypes.

Materials and methods

Germplasm. Twelve perennial flax genotypes used in previous CF and stock plant production research were used in the present study (Goodman and Anderson 2025; Goodman et al. 2023; Goodman EA, Anderson NO, Tong CBS, unpublished data). Genotypic code identifiers for the genotypes were CF1-CF10 and CF12-14. The germplasm represented a diversity of perennial flax responses to postharvest care and handling practices used by the floral industry, including three genotypes with the greatest potential for release as CFs. Genotypes CF2 and CF3 are *L. perenne* hybrids and CF1 is most likely that species as well (Abbey M, Anderson NO, unpublished data). *Linum austriacum* hybrids were identified as CF6, CF8, and CF 14; genotypes CF7, CF11, and CF13 are most likely interspecific hybrid combinations. Genotype CF5 is an interspecific hybrid of *L. perenne* × *L. lewisii,* whereas CF10 is a hybrid derivative of *L. bienne* Mill. but is an herbaceous perennial in US Department of Agriculture zones 3–4 (Goodman and Anderson 2025), despite the biennial life history of *L. bienne*.

Production conditions. Plants were field grown at the RROC [Rosemount Research and Outreach Center, Rosemount, MN, USA (44°42′58.2″N, −93°5′54.9″W)] under standard production conditions used by the UMN perennial flax breeding program CF research studies (Goodman and Anderson 2024, 2025; Goodman EA, Anderson NO, Tong CBS, unpublished data). Clonal ramets within each CF genotype were the identical clonal plants used previously.

Stems were harvested during weeks 38 to 44 (2023) with unbranched stem lengths >30 cm, more than two buds in color, no open flower buds, using the harvest protocols and postharvest (PH) handling established by Tork et al. (2022). Between 0800 and 1200 HR each day of harvest, flower stems were cut at the base of the plants using pruners (Corona, BP15180CCH, Corona, CA, USA) disinfected with 70% ethanol between plants. Cut stems were hydrated in deionized (DI) water, transported in a climate-controlled vehicle to the PH trial site (~20 miles), and rehydrated in fresh, room temperature (21 °C) DI water while processing. Stems from each genotype were kept separated in individual buckets until the experimental setup occurred.

Stem processing and experimental setup. Oasis® brand floral foam blocks (Oasis® Floral Products, 10 to 00020; Kent, OH, USA) were cut into one-third size blocks (measuring 10.5 cm length × 7.5 cm width × 7.5 cm height) using the cut lines provided at one-third markings on each block by the manufacturer. At the commencement of the experiment, the exposed surface area of each Oasis® brand floral foam block equaled 186.75 cm^2. The experiment consisted of n = 48 one-third blocks. A total of 24 blocks were submerged in DI water in clean buckets overnight before the start of the experiment. Because there are varying recommendations for fresh flower foam hydration of the blocks, varying from <1 min to a few hours (Oasis Floral Products 2025), we soaked all blocks overnight in the test solutions to ensure thorough hydration throughout the block. The remaining 24 blocks were placed in FloraLife Crystal Clear 300® powdered flower food (conventional, FL; #82-03042, FloraLife, Walterboro, SC, USA) preservative solution following the directions on the product instructions (10 g FloraLife 300®/L DI water) and submerged overnight for absorption of water and/or the floral preservative.

Stems were brought into the laboratory separated by genotype and kept in water. Before processing each genotype, n = 6 blocks of the submerged floral foam were each placed into a cleaned, labeled 6-inch single floral design bowl, style #73 (Syndicate Sales, 73-48-07, Kokomo, IN, USA) divided into three design bowls with DI water and three with the FloraLife solution. For each genotype, n = 18 stems (2 solution types × 3 repetitions × 3 different stem lengths) were cut. Stems were measured, based on the unbranched length, from the cut end to the first branch with buds and divided into three stem length groups (22.5, 16.25, and 10 cm). Excess stem length was cut off with sanitized clippers. Foliage was removed from the bottom half of each stem. Mature ovaries and dried seed pods were removed at the pedicel base with sanitized clippers to leave only unopened buds. For each stem, the total number of buds and number of colored buds were recorded, along with the diameter of the cut end measured with calipers before the stem was inserted into the foam block.

To test the stability of the stem, each stem was held at the defoliation point, and with a single firm push, the stem was inserted into the foam. The stem was then removed and the length of insertion was recorded (cm). If the stem bent, the length from the cut end to the bend was recorded (cm) as well as the stem diameter at the point of the bend. Stem bending was recorded as 0 (no bending) or 1 (bending). The angle of stem bending was not recorded because the angle of stem insertion approximated 90 degrees due to several genotypes having weaker stem strengths (data not shown). To account for this stem weakness, the stem diameter at the bend was recorded. Finally, the stem was reinserted into the previous insertion point. A total of n = 6 control floral bowls per genotype were tested for DI water (n = 3 bowls) or FloraLife solution (n = 3 bowls).

The completed design bowls were then placed on shelves in a completely randomized design with fluorescent lights on a 16-h-long day photoperiod to simulate a consumer home with overhead lighting using two Phillips F40T12/CW Supreme/ALTO Bi-pin fluorescent light bulbs (Phillips, 423889, Netherlands). Photosynthetically active radiation was measured three times on each shelf for the left, center, and right, to assess light variation. Measurements were taken using a LI-COR® Biosciences (Lincoln, NE, USA) light meter (Model LI-250A, serial #Q35167, cal. date 28 Jun 2005), yielding an average of 55.5 for the upper shelf and 50.4 for the lower shelf, averaging 52.9 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Once the design bowls were in place, an additional 100 mL (floral preservative) or 150 mL (control solution) of the respective solution was added to each design bowl.

Data collection. Data were collected within a 3-h range in the early afternoon (~1300–1430 HR) each day. Temperature (°C) and RH (%) were measured daily using digital hygrometers (ThermoPro®, model

TP49W). In addition, the number of open flowers (each marked with colored string after counting), the number of senesced flowers, the number of dropped flowers, and the number of dropped flower buds were recorded. A flower was classified as senesced when petal margins became rugose, rolled inward, petals dropped, or flowers were generally desiccated and unsightly (Goodman EA, Anderson NO, Tong CBS, unpublished data). A flower was classified as dropped when one or fewer petals remained. The minimum volume added to each floral bowl per day equaled 100 mL. Volume added per day was recorded as a binary volumetric amount (0 or 100 mL). Thus, if a vase required the addition of 50 mL, 0 mL would be added that day. The exception was for day 2 volumes, which were increased to 120 mL due to higher water loss at the onset of the experiment.

An assumption made for this experiment was that all blocks of floral foam remained fully saturated during the experiment and, because of equal floral foam block volumes, were equal in solution holding capacity. At the termination of the experiment, the volume remaining in each floral bowl was measured (mL). To calculate the total volume added across the experiment, the following equation was used:

Total volume added (mL) = Σ volume added (days 1 to 9)

The volume used in milliliters was calculated by subtracting the volume remaining (mL) from the total volume added (mL) using the following equation:

Volume used (mL) = Total volume added (mL) − Volume remaining (mL)

To calculate the volume used per stem, the volume used in milliliters was divided by the three stems placed in each floral foam block.

Average volume used per stem (mL) = Volume used (mL)/3 stems

The net volume used per floral bowl (mL) was calculated by first averaging the volume remaining (mL) of the control floral bowls for FloraLife preservative solution and DI water separately. This created mean evaporation loss for each solution type. Then the volume used from each bowl was subtracted by the mean control solution volume used to determine how much additional solution was used by each genotype. The net volume used per floral bowl equation was modeled from Vinodh and Kannan (2019):

Net Volume Used per Floral Bowl (mL) = Volume Used (mL) − Respective mean control solution volume used (evaporative loss)

The number of days with no solution added was calculated by finding the number of days in which no solution was added to a specific genotype in either DI or FloraLife across all days of the experiment. To calculate the percentage, the number of days was divided by 27 (9 d of the experiment × 3 reps) and multiplied by 100.

Data analysis. A univariate analysis of variance (ANOVA) was performed for quantitative traits with single measurement in time to assess differences among treatments and genotypes. Main effects included CF perennial flax genotypes and stem lengths tested for postharvest solution-related measurements: total volume added (mL), volume remaining (mL), volume used (mL), average volume used per stem (mL), net volume used per floral bowl (mL), number of days with no solution added, percent (%) of days with no solution added, and pH. Mean separations are based on Tukey's honestly significant difference test at $\alpha = 0.05$.

Multivariate analysis of variance (MANOVA) was performed for perennial flax genotypes, solution types, stem lengths, and their interactions for the number of individual opened flowers, number of senesced individual flowers, number of dropped buds, and number of dropped flowers per day (over the 9-d experimental period). Additional MANOVAs were conducted for CF perennial flax genotype, solution, and genotype by solution interaction for the volume of solution added on days 1 and 3 to 9.

Qualitative data were analyzed using χ^2 tests for equal distribution (1:1χ^2; df = 1) of rating of stem bending of perennial flax stems (0 = no bending, 1 = bending) after stem insertion into Oasis floral foam (n = 18/genotype) and for equal distribution (1:1χ^2) of rating of stem discoloration on stems (0 = no, 1 = yes) after the duration of the experiment.

Results

Genotypes were significant for all traits measured with the exception of

Table 1. Univariate analysis of variance for perennial flax genotypes, solution types, stem lengths, and their interactions and mean (pooled by genotype or stem length) separations for the number of total buds per stem, number of initial colored buds per stem, fraction of flowers opened, stem caliper at cut end (mm), stem depth in floral foam (cm), length of discoloration (cm), and flower diameters 1, 2, and 3 (mm) based on Tukey's honestly significant difference at $\alpha = 0.05$.

Effects	No. of total buds per stem	No. of initial colored buds per stem	Fraction opened	Stem diam at cut end (mm)	Stem depth in floral foam (cm)	Length of discoloration (cm)	Flower diam 1 (mm)	Flower diam 2 (mm)	Flower diam 3 (mm)
Genotype	***	***	***	***	***	***	***	NS	*
Solution type	**	NS	NS	**	***	***	***	***	***
Stem length	NS	**	NS	*	***	***	NS	NS	NS
Genotype × Solution	***	NS	NS	NS	***	***	NS	**	NS
Genotype × Stem length	NS	**	NS	NS	***	***	NS	NS	NS
Solution × Stem length	NS	NS	NS	NS	*	NS	NS	NS	NS
Genotype × Solution × Stem length	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.001$, respectively.

flower diameter 2, based on ANOVAs (Table 1). Although flower diameter 2 was not significant ($P = 0.094$), there were slight differences in the mean separations (Table 2). Solution type was significant for flower diameters 1, 2, and 3, number of total buds per stem, stem diameter at cut end, stem depth in foam, stem dislocation, and length of discoloration but insignificant for all other traits (Table 1). Stem length was only significant for initial colored buds per stem, stem depth in foam, and length of discoloration. Genotype and solution had significant interactions for the second flower diameter, number of total buds per stem, stem depth in foam, stem discoloration, and length of discoloration. The 2-way interactions between genotype and stem length showed four significant factors, whereas solution and stem length showed significance for only one factor. There were no significant three-way interactions (Table 1).

The number of total buds per stem differed significantly among CF genotypes, ranging from 3.94 (CF7) to 11.89 (CF8; Table 2). Genotypes CF1, CF2, CF7, CF13, and CF14 overlapped in significance for bud number, whereas all other CFs tested had significantly higher bud production. There were no significant differences between the number of total buds per stem across stem lengths, having a pooled mean of 7.9 (Table 2). The number of initial colored buds per stem ranged from 1.8 (CF13) to 4.2 (CF3), with significantly different groupings among genotypes occurring (Table 2). For this trait, the number of initial colored buds per stem differed for stem lengths, with the highest number (2.7) occurring in the lengthiest stem (22.5 cm) that overlapped with the 16.25-cm stem length but differed significantly from the shortest (10 cm; Table 2). The opposite trend was for stem diameter with 10-cm stems having significantly smaller stem diameters of 1.1 mm compared with the 22.5-cm stems with a diameter of 1.2 mm. Among genotypes, most stem diameters were the same (0.95 mm, CF14 to 1.2 mm, CF6-CF8, CF12) and the remaining genotypes were significantly larger. The fraction that opened flowers per stem did not differ among stem lengths (pooled mean = 0.4) although

Table 2. Mean separations of cut flower (CF) perennial flax genotypes and stem lengths (cm) for phenotypic traits measured in the experiment: number of total buds per stem, number of initial colored buds per stem, fraction opened, stem diameter at cut end (mm), stem depth in the floral foam (cm), and length of discoloration (cm). Mean separations (lowercase letters) are based on Tukey's honestly significant difference test at α = 0.05. Means among genotypes were pooled if the trait was not significant.

CF genotype or stem length (cm)	No. of total buds per stem	No. of initial colored buds per stem	Fraction opened	Stem diam at cut end (mm)	Stem depth in floral foam (cm)	Length of discoloration (cm)	Flower diam 1 (mm)	Flower diam 2 (mm)	Flower diam 3 (mm)
Genotype									
CF1	6.28 a–c	2.28 a–c	0.396 bc	1.0500 ab	5.3278 b	11.472 d	23.244 a–c	24.394 a–c	23.776 ab
CF2	6.44a–c	2.78 b–d	0.445 b–d	1.3111 b–d	4.4444 a	5.981 b	29.293 fg	26.133 bc	24.378 ab
CF3	10.06 d–f	4.17 g	0.427 bc	1.3278 cd	4.0556 a	8.208 c	26.272 c–g	24.606 a–c	25.164 ab
CF4	7.72 cd	3.00 c–e	0.392 bc	1.0222 a	5.6389 b–d	6.011 b	28.218 e–g	25.829 bc	26.470 b
CF5	10.72 ef	3.78 fg	0.361 ab	1.1111 a–c	5.4278 bc	7.165 bc	28.650 e–g	27.231 c	25.991 b
CF6	9.17 de	2.28 a–c	0.249 a	1.1500 a–d	5.9444 c–e	8.656 c	25.806 b–f	23.856 a–c	25.350 ab
CF7	3.94 a	2.06 ab	0.582 d	1.2167 a–d	5.9000 b–e	8.233 c	20.650 a	19.993 a	22.120 ab
CF8	11.89 f	3.61 e–g	0.319 ab	1.1778 a–d	5.6611 b–e	8.047 c	22.311 ab	21.850 ab	20.267 a
CF10	11.50 ef	3.89 fg	0.347 ab	1.4111 d	6.0389 de	7.571 bc	29.933 g	25.433 bc	22.969 ab
CF12	7.56 b–d	3.00 c–e	0.419 bc	1.1778 a–d	6.2500 e	3.800 a	27.428 d–g	24.519 a–c	23.717 ab
CF13	4.83 a	1.83 a	0.392 bc	0.9611 a	5.7639 b–e	8.006 c	24.261 a–d	22.869 a–c	23.933 ab
CF14	5.00 ab	2.33 a–c	0.510 cd	0.9472 a	5.8750 b–e	7.344 bc	25.1 b–e	24.271 a–c	23.409 ab
Stem length (cm)									
10.0		3.15 b		1.0958 a	3.8208 a	6.334 a			
16.25		2.88 ab		1.1681 ab	5.6889 b	7.565 b			
22.5		2.72 a		1.2021 b	7.0722 c	8.812 c			
Pooled	7.926		0.404						

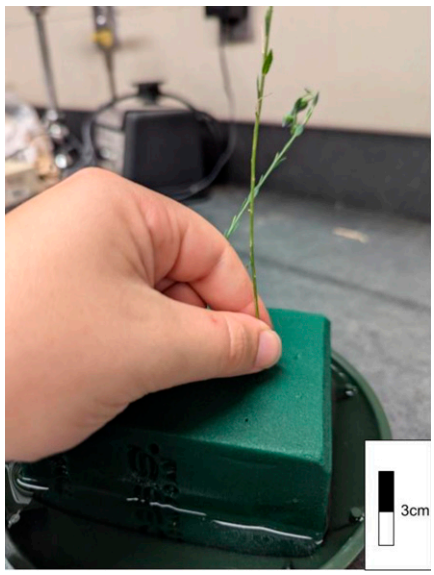

Fig. 1. Stem depth in floral foam measurement on perennial flax during experiment setup (photo credit: Julia Stuenkel). Scale bar = 3 cm.

genotypic means differed widely in significance (Table 2).

Stem depth in foam showed significance among all three stem lengths (Fig. 1), such that the mean overall shortest lengths (10 cm) were significantly less than each of the other two increasing lengths (Table 1). The same trend was found for the mean length of discoloration of the stems for each stem length. Genotypes CF2 and CF3 had the least penetrance into the floral foam (~4.0 to 4.4 cm, respectively) and CF6-CF8, CF10, and CF12-14 having significantly greater depths (Table 2). Length of the discoloration of stem lengths differed widely among genotypes, with the significantly lowest being CF 12 (3.8 cm) to the longest in CF1 (11.5 cm).

Genotype significantly affected the solution uptake, as measured by the total volume added per floral bowl (mL), the volume used per floral bowl (mL), the average volume used per stem (mL), and the calculated volume evaporated (Table 3). Solution type was insignificant for all factors except the calculated volume evaporated; the two-way interactions were insignificant for all factors (Table 3). The pH of the final solution was insignificant for all factors. The number and percent (%) of days when no solution was added to experimental units were insignificant for genotype. The solution type was very highly significant for only the net volume used per floral bowl; none of the genotype × solution interactions were significant for any solution-related measurements (Table 3).

The first flower diameter on each stem ranged from 20.6 to 29.9 for genotypes CF7 and CF10 (Table 2), respectively. The second flower diameter ranged from 20.0 (CF7) to 27.2 (CF5). The third flower ranged from 20.3 (CF8) to 26.5 (CF4) (Table 2). The initial number of colored buds per stem differed with a range from 1.8 (CF13) to 4.2 (CF3), whereas the fraction of buds opened over the course of the experiment ranged from 0.2 (CF6) to 0.6 (CF7; Table 2). Stem diameters at the cut end ranged from 0.95 mm (CF14) to 1.4 mm (CF10). Despite the variety of stem diameters, the depth of the stem in foam was not impacted, with depths ranging from 4.0 cm (CF3) to 6.2 cm (CF12). The length of discoloration ranged from 3.8 cm (CF12) to 11.5 cm (CF1; Table 2).

The total volume added to the floral bowls was lowest for the DI water control bowl and CF8 with an average of 766.7 mL added over the 9-d trial (Table 4). However, the FloraLife solution control had 920 mL added, which was significantly different from the DI water control and CF8 and overlapped with all other genotypes (Table 4). CF7 had the most water added (936.7 mL). The calculated volume evaporated ranged from −70.50 mL (CF10) to 101.67 mL (CF7) with only CF10 and CF7 having a significant difference. There were no significant differences in volume remaining across the genotypes with a pooled mean of 76.8 mL. In addition, there was no significant difference in the percentage of days where no solution was added with a pooled mean of 21.30% (Table 4). Volume used ranged from 694.2 mL (CF10) to 866.3 mL (CF7) with only CF10 and the DI control showing a significant difference compared with CF7. The same trend was observed with the average volume used per stem (Table 4), whereas the number of total buds per stem ranged from 3.9 (CF7) to 11.9 (CF8; Table 1).

Solution pH levels were not significant among genotypes, solution types, nor their interaction (Table 3). As would be expected, the lowest (most acidic) pH occurred with the FloraLife preservative, as low as pH = 2.4 (CF1) and a pooled mean of pH = 2.61 for this solution treatment. In contrast, the DI water control with a pooled mean of pH = 3.37 reached levels as high as pH = 4.75 (CF1). The pooled mean across both treatments was pH = 2.99.

Repeated measures (daily on the same ramets of each genotype) MANOVA showed genotypes and solution types varying significantly for the number of opened flowers per day, the number of senesced flowers per day, the number of dropped buds per day, and the number of flowers per day (Table 5). In contrast, however, stem length was insignificant for all traits in these analyses. The two-way interactions between genotype and solution were significant for all traits. As would be expected, any two- and three-way interactions involving stem length (a nonsignificant main effect) were also not significant, with the notable exception of the number of dropped buds per day (genotype × stem length; genotype × solution × stem length; Table 5) except for solution and stem length.

In the repeated measures MANOVAs for total solution volumes added per day (days 1, 3 to 9) per floral bowl, genotypic effects were significant only on days 1 and 3 (Table 6). There were no genotypic differences in solution added on days 4 to 9. Solution types were not significant across days 1 to 9 with the notable exception of day 7 (Table 6). The only significant genotypes × solution interaction was for day 8. Thus, with the exception of day 7, the volumes added for days 4 to 6 and 8 to 9 were pooled by genotype and solution (Table 7). The volume added for day 7 was significantly greater (93.0 mL) for FloraLife than the DI water (71.4 mL) (Table 7).

Among the different genotypes on the first day solution was added, CF1, CF6, CF7, and the control FloraLife solution were significantly different from all other genotypes and the DI control (Table 7). On day 2, 120 mL or 100 mL of solution was added to all of the genotypes and control vases and, thus, day 2 is not included. For day 3, CF1, CF6, CF7, CF13, CF14, and the FloraLife control had significantly more

Table 3. Univariate analysis of variance for perennial flax genotypes, solution types, and their interactions for total volume added (mL), total volume remaining (mL), volume used (mL), average volume used per stem (mL), net volume used per floral bowl (mL), number of days with no solution added, percentage (%) of days with no solution added, and pH.

Main effects	Total volume added (mL)	Volume remaining (mL)	Volume used (mL)	Avg volume used per stem (mL)	Net volume used per floral bowl (mL)	No. of days with no solution added	Percentage (%) of days with no solution added	pH
Genotype	***	NS	**	**	*	NS	NS	NS
Solution type	NS	NS	NS	NS	***	–	–	NS
Genotype × Solution	NS	NS	NS	NS	NS	–	–	NS

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.001$, respectively.

Table 4. Mean separations of cut flower (CF) perennial flax genotypes and stem lengths (cm) for postharvest solution-related measurements: total volume added (mL), volume remaining (mL), volume used (mL), average volume used per stem (mL), net volume used per floral bowl (mL), number of days with no solution added, percent (%) of days with no solution added, and pH. Mean separations (lowercase letters) are based on Tukey's honestly significant difference test at α = 0.05. Means among genotypes were pooled if the trait was not significant, based on analysis of variance.

Genotype or solution type	Total volume added (mL)	Volume remaining (mL)	Volume used (mL)	Avg volume used per stem (mL)	Net volume used per floral bowl (mL)	No. of days with no solution added	Percent (%) of days with no solution added	pH
Genotype								
CF1	886.7 a–c		824.7 ab	274.9 ab	60.0 ab			
CF2	816.7 a–c		742.5 ab	247.5 ab	−22.2 ab			
CF3	816.7 a–c		736.3 ab	245.4 ab	−28.3 ab			
CF4	816.7 a–c		775.0 ab	258.3 ab	10.3 ab			
CF5	833.3 a–c		744.2 ab	248.0 ab	−20.5 ab			
CF6	903.3 a–c		831.8 ab	277.3 ab	67.2 ab			
CF7	936.7 c		866.3 b	288.8 b	101.7 b			
CF8	766.7 a		711.8 ab	237.3 ab	−53.8 ab			
CF10	783.3 ab		694.2 a	231.3 a	−70.5 a			
CF12	800.0 a–c		709.3 ab	236.4 ab	−55.3 ab			
CF13	836.7 a–c		751.8 ab	250.6 ab	−12.8 ab			
CF14	853.3 a–c		775.5 ab	258.5 ab	10.8 ab			
Solution type								
DI control	766.7 a		704.7 a	234.9 a	n/a[i]			
FloraLife control	920.0 bc		824.7 ab	274.9 ab	n/a[i]			
Pooled		79.1				5.8	21.3	2.99

[i] n/a denotes not applicable.

solution volume added to them than all others. No significant difference in solution volume added was observed on days 4 to 9 and the pooled means ranged from 65.3 mL (day 9) to 98.7 mL (day 4) (Table 7).

Although not significant, examples of the variability among genotypes and solution volumes added per day during days 4 to 9, showed on day 4 all floral bowls received 100 mL of water except for one FloraLife solution

Table 5. Multivariate analysis of variance for perennial flax genotypes, solution types, stem lengths, and their interactions for the number of individual opened flowers, number of senesced individual flowers, number of dropped buds, number of dropped flowers per day (over the 9-d experimental period).

Main effects	No. of opened flowers per day	No. of senesced flowers per day	No. of dropped buds per day	No. of dropped flowers per day
Genotype	***	***	***	***
Solution type	***	***	***	***
Stem length	NS	NS	NS	NS
Genotype × Solution	***	**	***	***
Genotype × Stem length	NS	NS	**	NS
Solution × Stem length	NS	NS	NS	NS
Genotype × Solution × Stem length	NS	NS	**	NS

NS, **, *** Nonsignificant or significant at $P \leq 0.01$ or $P \leq 0.001$, respectively.

Table 6. Multivariate analysis of variance for cut flower perennial flax genotype, solution, and genotype by solution interaction for the volume of solution added days 1 and 3 to 9.

	Volume of solution added							
Main effects	Day 1	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Genotype	***	***	NS	NS	NS	NS	NS	NS
Solution	NS	NS	NS	NS	NS	**	NS	NS
Genotype × Solution	NS	NS	NS	NS	NS	NS	**	NS

NS, **, *** Nonsignificant or significant at $P \leq 0.01$ or $P \leq 0.001$, respectively.

bowl, whereas on day 5, three DI bowls and one FloraLife solution bowl had 0 mL applied (data not shown due to pooling). Eight DI and nine FloraLife solution bowls did not receive additional solutions on day 6. On day 7, 12 DI and two FloraLife solution bowls did not receive additional solution; for day 8, four DI bowls and eight FloraLife solution bowls did not receive additional solution. Solution type was only significant for volume added on day 7, as noted earlier (Tables 6 and 7). Finally, on day 9, 14 DI bowls and 15 FloraLife solution bowls did not receive additional solution.

For all genotypes, with the exception of CF13, most stems within each genotype did not have stem bending on insertion into the floral foam blocks (Table 8). Thus, for these genotypes there was not an equal chance of stem bending on the insertion into Oasis floral foam. There were differences in significance in deviation from the 1:1 χ^2 where CF14 was significantly different ($P \leq 0.05$) and the remaining genotypes (with the exception of CF13) were very highly significantly different from the 1:1 χ^2 test ($P \leq 0.001$). CF13 had an equal ratio of stems bent to those that did not bend and thus fit a 1:1 χ^2 (Table 8).

For all genotypes with the exception of CF3, most stems within each genotype had stem discoloration (Table 8), defined as either chlorosis or necrosis. For these genotypes there was not an equal observation of discoloration at the end of the trial. There were differences in significance in the deviation from the 1:1 χ^2 where CF12 was highly significantly different ($P \leq 0.01$), whereas the remaining genotypes (with the exception of CF3) were very highly significantly different ($P \leq 0.001$). Genotype CF3 had five stems with no discoloration at the end of the experiment and fit the 1:1 χ^2 test (Table 8).

Discussion

Genetic effects (genotypes) significantly affected all of the traits except for flower diameter 2. Genotypes have proven significant in previous perennial flax CF postharvest research (Goodman et al. 2023; Tork et al. 2022; Goodman EA, Anderson NO, Tong CBS, unpublished data). Because flower diameters 1 and 3 were significant for genotypes, the diameter for flower 2 was consistently insignificant across all genotypes. It is unclear why this would be the case but it is unclear whether this flower can be ignored in future research, because floral development of flowers 1 and 2 would be sequentially different at harvest, which could be a confounding effect. Thus, further research would be required to determine the cause(s) of these results. Thus, to avoid time delays, measuring the first flower only would suffice to make estimates of

Table 7. Multivariate analysis of variance for cut flower (CF) perennial flax genotype and vase solution mean separations for total solution volumes added per day (days 1 and 3 to 9; lowercase letters) based on Tukey's honestly significant differences at α = 0.05. Means among genotypes were pooled if the trait was not significant, based on analysis of variance.

	Volume (mL) of solution added							
Genotype or solutions	Day 1	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Genotype								
CF1	0.0 a	100.0 b						
CF2	100.0 b	0.0 a						
CF3	100.0 b	0.0 a						
CF4	100.0 b	0.0 a						
CF5	100.0 b	0.0 a						
CF6	0.0 a	100.0 b						
CF7	0.00 a	100.0 b						
CF8	100.0 b	0.0 a						
CF10	100.0 b	0.0 a						
CF12	100.0 b	0.0 a						
CF13	100.0 b	100.0 b						
CF14	100.0 b	100.0 b						
CF21	100.0 b	0.0 a						
CF22	0.00 a	100.0 b						
Pooled			98.7	94.7	80.3	82.4	84.2	65.4
Solutions								
DI water						71.4 a		
FloraLife solution						93.0 b		

Table 8. χ^2 test for equal distribution (1:1; df = 1) of rating of stem bending of perennial flax stems (0 = no bending, 1 = bending) after stem insertion into Oasis floral foam (n = 18/genotype) and for equal distribution (1:1) of rating of stem discoloration on stems (0 = no, 1 = yes) after duration of the experiment. Stem lengths were pooled due to lack of significance. CF = cut flower.

	Rating of stem bending			Rating of stem discoloration		
Genotype	No (0)	Yes (1)	1:1 χ^2	No (0)	Yes (1)	1:1 χ^2
CF1	18	0	18.0***	0	18	18.0***
CF2	18	0	18.0***	2	16	10.9***
CF3	18	0	18.0***	5	13	3.6 NS
CF4	16	2	10.9***	0	18	18.0***
CF5	16	2	10.9***	1	17	14.2***
CF6	16	2	10.9***	0	18	18.0***
CF7	17	1	14.2***	0	18	18.0***
CF8	18	0	18.0***	1	17	14.2***
CF10	18	0	18.0***	1	17	14.2***
CF12	17	1	14.2***	3	15	8.0 **
CF13	9	9	0.0 NS	0	18	18.0***
CF14	14	4	5.6*	0	18	18.0***

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.001$, respectively.

flower size. This interesting anomaly is worthy of future study to determine why the first and third flowers differ from the second. Likewise, breeding and selection for genotypes (seedlings) with superior phenotypic traits is achievable, given the significant effects that genotypes had on almost all traits evaluated.

Flower diameters 1 or 3 could be used to select large-flowered genotypes in the breeding program. Genotype CF4 was in the significantly largest flower diameter group for both (Table 2). CF10 had the highest flower diameter but overlapped with CF2-CF5 and CF12. CF10 is still in the largest group for flower diameter 3; however, CF4 is the highest. Thus, a plant breeder could select any genotype in the highest mean diameter of flower 1 and be assured any genotype would also be in the largest grouping for flower diameter 3. Future research should focus on the heritability of flower diameter to increase their potential size—an important criterion for floriculture and floral design in particular as a component of "flower power" (Anderson 2006; Drew et al. 2010).

Fig. 2. Experiment setup on day 0 of perennial flax postharvest performance experiment (photo credit: Julia Stuenkel). Scale Bar = 5 cm.

In addition, a flower breeder would want to consider the number of buds per stem, which was found to differ significantly among genotypes (Table 1). For example, CF8 had the highest number of total buds per stem, but did not differ from CF3, CF5, and CF10 (Table 2). Thus, intermating these three genotypes could be a source of an increased number of flowers, provided the trait has high heritability. The highest number of initial colored buds per stem had the same genotypes, but CF3 had the largest average number of colored buds per stem. Due to perennial flax's short individual flower life span (Goodman et al. 2023, 2024; Tork et al. 2022; Goodman EA, Anderson NO, Tong CBS, unpublished data), more flower buds on each stem potentially increases the overall postharvest longevity (vase life) of each perennial flax CF stem. However, when evaluating this increase in conjunction with the fraction of flowers that opened per stem, CF8 was in the significantly smallest group (Table 2). Genotypes that had the significantly largest fraction open (CF2, CF7, and CF15) were in the significantly smallest group for the total number of buds (Table 2). More flowers mean a longer floral display time in floral designs, another component of flower power (Anderson 2006; Drew et al. 2010). A breeder must determine which of these two traits is the most important, as breeding these negatively correlated traits would be difficult until linkage(s) is broken.

A major concern with perennial flax becoming a specialty CF crop is the relatively thin stems of the CFs (Hunter 2013). This is especially concerning if flax were to be used in floral designs using floral foam (Figs. 1 and 2). Despite relative differences in the stem diameter among genotypes, the χ^2 test showed that only CF13 stems had a significant tendency to bend, regardless of length (Table 8). In addition, five genotypes had no stems bent on insertion into the floral foam. Of those five genotypes, CF2, CF3, CF8, and CF10 were in the significantly largest group for stem diameter, notably genotype CF1, was in the smallest group for stem diameter (Table 2). Therefore, stem diameter is not a predictive measure for whether a genotype-specific stem will bend when inserted into floral foam. Future research to select nonbending stems of genotypes will require conducting these tests.

Stem depth in floral foam was significantly different among genotypes (Table 2). That stem strength can influence the depth of stem insertion is genotype-dependent. As such, it should be an easily selected phenotype for breeding CF perennial flax.

An issue that has been noted in previous postharvest research on perennial flax has been issues of stem discoloration (Goodman et al. 2023, 2024; Tork et al. 2022; Goodman EA, Anderson NO, Tong CBS, unpublished data). In the present study,

stem discoloration was marked as any chlorosis or necrosis of the stem tissue along with any fungal growth. The 1:1 χ^2 stem discoloration test for CF3 was the only one that was not significant, indicating there was an equal likelihood of it occurring (Table 8). All other genotypes showed significance having the most stems with discoloration and fungal growth. Thus, genotype CF3 should be used in breeding programs to lower the likelihood of stem discoloration. In addition to the differences in the number of stems with discoloration, the length of stem discoloration by genotype differed significantly (Table 1). The widespread issue of discoloration and fungal growth in this experiment is worthy of further research and breeding efforts to minimize stem discoloration.

Stem length differences had no significant effects for most traits measured in this experiment except for the number of initial colored buds per stem, stem diameter at cut end, and stem depth in floral foam (Table 1). Traits that remained insignificant across stem lengths also provide critical information to breeders and florists to determine the proper stem lengths for CF bunching.

Flower diameter was not significantly impacted by the length of the stem for the first three flowers that opened. Based on this observation, a florist can cut flax stems to any length and the flower diameter for at least the first three flowers will not be compromised in a floral design. Despite stem length being a major consideration in the cut floral industry (Anderson 2006; Diehl Scace and DelPrince 2023; Dole and Wilkins 2005; Hunter 2013), this characteristic may have little impact on flower quality including size (Reid 2004), as found in this study. When harvesting any CF crop, the grower always maximizes stem length because it can significantly influence price (e.g., in roses), as well as providing wholesalers and florists maximum stem lengths for use in floral designs (Anderson 2006; Diehl Scace and DelPrince 2023; Dole and Wilkins 2005; Hunter 2013).

Total buds per stem was not significant across stem lengths, unlike the number of initial buds per stem (Table 1). Future research should clarify why the number of initial colored buds was significantly different, whereas the total number of buds was not significant among stem lengths. In addition, the fraction of buds that opened was not significant for stem length, meaning that the number of initial colored buds per stem is not an indicator of the number of flowers that will open.

Stem diameter was significantly different among the stem lengths, with the shortest stems having the smallest diameter and the longest stems having the largest diameter and the middle stem length overlapping in significance (Tables 1 and 2). Unlike the genotypes, stem length differences show a clear relationship between stem diameter and depth inserted into the foam with the largest stem diameter able to be inserted the deepest into the foam (7.1 cm; pooled) and the smallest stem diameter only able to penetrate as deep as 3.8 cm (Table 2). Larger stem diameters have less occurrences of stem bending. Therefore, in floral designs using perennial flax, genotypes with thicker stems should be used or florists should consider using longer stems to prevent bending. Otherwise tying or binding multiple stems together would be required, a practice commonly instituted with other CF crops with delicate stems used as filler material (e.g., perennial baby's breath, *Gypsophila paniculata* L.) (Diehl Scace and DelPrince 2023; Hunter 2013).

Solution type had a significant impact on most traits, excluding the number of initial buds per stem and fraction opened. However, the solution type was not significant for the number of days with no solution added (Tables 3 and 4). Florists or retail consumers would not have to add significantly more solution when using FloraLife® preservative solution compared with DI water. Regardless of the solution type, CF7 used significantly more solution than CF10, demonstrating genetic (genotypic) differences in solution uptake. Solution uptake should be a selection criterion in the breeding program to minimize solution uptake while simultaneously maximizing postharvest vase life.

The volume of preservative solution evaporated may be influenced by the higher floral foam surface area (186.75 cm^2) due to testing only three stems per block. The routine practice in floral design is to cover the floral foam with foliage or moss to "hide" the mechanics, which not only reduces evaporation potential but also creates a more visually appealing floral design (Diehl Scace and DelPrince 2023; Hunter 2013). Although this effect is equalized across treatments, additional experiments should be conducted to determine the calculated volume evaporated when the floral foam is covered. Likewise, once the new, sustainable and compostable floral foam replacements, (e.g., polylactide foams) (Dirlam et al. 2019; Goldfeld 2023, 2024) become commercially available, future studies would be warranted using perennial CF flax in this mechanic.

Conclusions

Despite perennial flax's thinner stems for use as a filler flower, it can be used in standard floral foam, which is the most commonly used mechanic in floral designs. There are significant differences among CF genotypes for most of the postharvest traits examined, indicating that future plant breeding efforts can select among genotypes and the critical physiological traits to maximize postharvest longevity of this new CF crop.

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