

**Post Harvest Handling Methods for Enhanced Competitiveness of Fresh Cut
Peonies**

**Part 1.
Vase Life Studies**

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2014 Student interns: Ruth Osborne and Makenzie Stamey
2013 Student interns: Melissa Pietila and Kathryn Mihalcz

**Part 2.
Effect of Boron and Calcium Sprays on Stem Strength of Peonies**

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RESEARCH REPORT

to:

Alaska Department of Natural Resources
Division of Agriculture
Alaska Specialty Crops Research Initiative



Post Harvest Handling Methods for Enhanced Competitiveness of Fresh Cut Peonies

University of Alaska Fairbanks

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Joint Summary. The University of Alaska Fairbanks in cooperation with Alaska peony growers conducted a series of experiments to establish standards for best quality fresh cut flowers to meet or exceed rigorous international industry requirements. Preliminary research at UAF found that chilling at 34°F for 1 week, doubled the vase life of peonies, and data from 2013 season corroborates those findings. However, vase life for cut flowers in 2014 decreased significantly and did not improve with chilling. Vase life for ‘Sarah Bernhardt’ and ‘Duchess de Nemours’ peonies averaged 6.1 days and 5.9 days, respectively for the entire treatment period and did not differ from the un-chilled control. Because of the unexpected results from 2014, this research did not clearly identify minimum chilling requirements for Alaska peonies. In contrast, cut stems in 2013 showed a linear increase in vase life with chilling (8.2 to 14.2 days for ‘Sarah Bernhardt’ and 6.9 to 13 days for ‘Duchess de Nemours’). Vase life and bud diameter did not differ among early- mid- and late-season cutting dates for both cultivars. Cut stems from two commercial farms showed the same short vase life, and there was no statistical difference in vase life among farms. These studies do not corroborate the statement that vase life of Alaska peonies is double the national standard. Environmental factors during spring growth or post harvest handling differences play a more significant role in defining vase life than simply hours of chilling (deliverables b,c,e).

Vase life for 68 cultivars in 2014 ranged from 4 days to 9 days (mean 6.0 ± 1.0 days). In 2013, vase life averaged nearly three days longer, 8.6 ± 2.7 days (range 4 – 14 days).. Vase life for 2014 was significantly lower for most cultivars than 2013. In 2013, more than 70 percent of the cultivars showed an average vase life of 7 days or more, while in 2014, only 24 percent reached that standard. The four main classifications of peonies grown at the botanical garden (semi-double, Japanese, bomb and full double) had an average vase life ranging from 5 days to 17 days. One classification had a vase life of less than 7 days for both 2013 and 2014, the Intersectional hybrids. (deliverable 1d)

Plants sprayed with Boron (B), calcium (Ca) and potassium (K) showed foliar absorption of B, but not Ca and K. No spray solution improved stem strength or increased stem diameter in 2014. The machine invented to determine bending distance prior to breaking fell short of our goal. Additional work on methods of securing the peony stems in the machine is needed to reduce errors. (deliverable 1a)

Part 1. Vase Life Studies

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Introduction

World cut flower sales are a highly competitive, volatile and multi-billion dollar industry (Highbeam Business 2012, Sarkar 2012, USDA 2013). Sales are subject to

fashion whims of consumers as well as industry demands for quality blooms that meet bud size standards and ship well; a product that has the requisite stem length/strength; and one with a long vase life. Since the product is a senescing (dying) stem, the industry has the daunting task of delivering a product whose consumer life is as long and colorful as possible (The reported consumer life for peonies is 7 days [Dole and Wilkin 2005]). Cut flowers must meet rigorous standards or they will be replaced by a myriad of other available specialty cuts from around the world (H.R.Kennicott, Kennicott Kutts, Ltd. Chicago, IL. pers. comm. 2012). The Alaska peony industry must meet these standards yet fit with the cultural conditions, climate and distribution system of Alaska. Every stage of plant production, from cultivation, harvest, post harvest handling, and shipping, impacts product quality.

UAF researchers began studying production chain management in 2001 (Auer 2008, Auer & Greenberg 2009, Auer & Holloway 2008, Holloway & Hanscom 2007, Holloway *et al.* 2003, 2004, 2005, 2010, Holloway & Buchholz 2013, Klingman 2002). The Alaska peony industry reached a milestone in 2012. More than 25,000 fresh cut peonies entered domestic and international markets (Holloway & Buchholz 2013), and production increased to 32,000 stems in 2013 (American Flower Farmer LLC 2014). Alaska growers must know and understand product quality, and a policy of exporting only top grade peonies must be established. Growers need to define what a quality brand is and work toward world recognition.

Preliminary research at UAF found that chilling at 34°F for 1 week doubled the vase life of peonies, but 12 hours was not sufficient. We want to determine the minimum time necessary for chilling prior to shipping for maximum consumer vase life. Some growers actually ship the day of harvest, which may not lead to the best product. One of our experiments hinted that vase life of Alaska peonies is double that of the Lower 48. We will repeat this experiment to verify those data so growers can demonstrate one more unique feature for marketing Alaska peonies. The UAF Experiment Station has a collection of 110 peony cultivars (Holloway 2013). We will determine the maximum vase life for all these cultivars so growers can rank them for quality. We will also conduct an experiment to identify differences in vase life with ‘Sarah Bernhardt’ peonies from Alaska farms to identify quality variations within the industry.

Methods

Experiment 1. Impact of cold storage time on vase life of ‘Sarah Bernhardt and Duchess de Nemours’ peonies. Goal: to establish the minimum time necessary for chilling prior to shipping for maximum consumer vase of fresh cut peonies. An experiment (4 replicates, 5 stems per rep) was performed that exposed fresh cut stems of two cultivars, ‘Sarah Bernhardt’, ‘Duchess de Nemours’, to a series of cold treatments (24, 48, 72, 96, 120, 144, 168 hrs in 2013 and 0, 48, 96, 144, 192, 240, 288 and 336 hours in 2014) at a target 34°F degrees.

All stems were harvested from the peony fields at the UAF Georgeson Botanical Garden, Fairbanks, Alaska. Cut stems were harvested beginning 1 July in both 2013 and

2014, cut to uniform stem length (24 inches), and wrapped in newspaper. In 2013, bundles were moved immediately after processing to a laboratory cooler. In 2014, the refrigeration unit was changed to a Conex cooler with an air conditioner/CoolBot® refrigeration unit/controller. Both environments were equipped with Hobo® data loggers (Onset Computer Corp.) for hourly records of air temperature and relative humidity. In addition, field air and soil temperature and relative humidity were recorded at the Fairbanks Experiment Farm using the same data loggers with sensors at a 30-inch height for air and 6-inch depth for soil.

In 2013, flowers were held in newspaper sleeves, in the dark and un-hydrated for 8 chilling treatments that included a control (no chilling) followed by chilling up to 7 days (24, 48, 72, 96, 120, 144, 168 hours). In 2014, the experiment was extended to 14 days at 2-day intervals (0, 48, 96, 144, 192, 240, 288 and 336 hours). Following treatment, the chilled stems were removed from refrigeration and placed in jars of tap water in a laboratory with 24-hr fluorescent lights ($25 \mu\text{M m}^{-2} \text{s}^{-1}$ measured 4 ft beneath the fixtures) supplemented with natural lighting from laboratory windows, and ambient room temperature. Flowers were observed daily, and, stems were gently tapped to release petals if an abscission layer had formed. The date of petal wilt or petal fall on chilled and un-chilled cut stems was recorded. Air temperature and relative humidity were recorded hourly in cold storage and in the laboratory. Data were analyzed using regression analysis for total vase life and hours of chilling during two cutting seasons, 2013 and 2014.

Experiment 2. Vase life of early, mid and late season buds of ‘Sarah Bernhardt’ and ‘Duchess de Nemours’ cultivars. Goal: to establish that Alaska peonies have a vase life that is equal to or significantly longer than the 7 days reported for peonies in world markets and to determine if there are any differences among cutting dates. Peonies of two cultivars, ‘Sarah Bernhardt’ and ‘Duchess de Nemours’, were harvested on three dates, 1, 10 and 20 July, 2014 (6 stems per cultivar, 3 replicates on each date). Half were placed immediately into jars of tap water and the remainder were refrigerated for 7 days in a Conex/CoolBot® cooler. Handling in the cooler and subsequent vase life studies were the same as Experiment 1. Data were analyzed using analysis of variance for chilled and un-chilled flowers for three harvest dates.

Experiment 3. Cultivar vase life at the Georgeson Botanical Garden. Vase studies were conducted in 2013 and 2014 on 110 peony cultivars growing at UAF Georgeson Botanical Garden. Goal: show variability among cultivars, identify cultivars with the longest vase life, and show vase life differences among peony classes (single, double, Japanese, semi-double, bomb, Intersectional) by determining optimum vase life compared to national average (7 days). Six cut stems of each cultivar were harvested as they reached Stage 3 bud maturity index (Holloway and Pietila 2012). They were chilled for 7 days, then evaluated for vase life as described in Experiment 1. Cultivars were categorized according to flower classification to learn the range, mean and median vase life for each category. Only cultivars harvested both in 2013 and 2014 were subject to analysis of variance (6 stems per replicate, 3 replicates) for differences among cultivars and years.

Experiment 4. Vase life trials among commercial Alaska growers. Goal: to identify possible variations in product vase life due to diverse growing, handling and shipping conditions of individual growers. Ten growers in Alaska’s interior were asked to submit 12 randomly cut stems of ‘Sarah Bernhardt’ peonies to a local pack house. These pack houses recorded methods of handling (cooler temperatures, relative humidity) for 7 days after which they were transferred to UAF, placed in jars of tap water, and evaluated for vase life.

Results and Discussion

After the 2014 season, growers were convinced that the 2013 and 2014 seasons were complete opposites in relation to temperatures and rainfall, but seasonal average air temperatures were very similar (Table 1). The 2013 season was warmer in June and July than 2014, and thaw degree-days differed by only 138 units. The most significant difference was rainfall that was 8.61 inches greater in 2014 than 2013. In 2013, Interior residents had few complaints about the weather; it was hot and dry early in the season, then moderated in August and September. All horticultural and agronomic crops that were not irrigated suffered severe losses due to water deficits in 2013. In 2014, temperatures were much cooler during the peak peony harvest season, and beginning about the third week of June, rainfall was nearly constant. Rainfall in 2014 eclipsed the highest seasonal rainfall recorded in the past 25 years by 2.71 inches.

Table 1 Temperature and rainfall records for the UAF Fairbanks Experiment Farm during 2013 and 2014 growing seasons.

Growing season weather statistics*	Year	
	2013	2014
Average seasonal air temp (F)*	53.9	55.9
Air temp (F) (max – min)	92.0 (27 Jun) – 16.9 (6 May)	84.2 (7 Jul) - 29.3 (30 Aug)
May (mean) (F)	42.2	48.9
June	64.5	56.4
July	62.8	58.3
Aug	58.2	57.5
Sept	41.9	42.6
Date of last spring frost	22 May	21 May
Date of first autumn frost	25 Aug	30 Aug
Previous Winter Min (F)	-45.3 (27 Jan 2013)	-41.6 (13 Jan 2014)
Rainfall (inches)**	5.42	14.03
Thaw degree-days (base temperature 32F)	3360	3222

*1 May – 30 Sept, from Agricultural and Forestry Experiment Station weather station.

The temperature and relative humidity levels in the laboratory remained fairly constant in 2013 and 2014 (Table 2). Because of lack of space, we changed cold storage facilities between years. Temperatures were similar between refrigeration units, but relative humidity was lower in the laboratory unit.

Table 2. Data logger averages for the post harvest laboratory and two cold storage facilities at UAF.

Controlled Environment Records				
	Refrigeration (Lab) 2013	Refrigeration Conex 2014	Post harvest lab 2013	Post harvest lab 2014
Air temperature (mean \pm SD) ($^{\circ}$ F)	34.8 \pm 2.2	33.8 \pm 3.6	69.4 \pm 1.6	70.5 \pm 1.5
Average relative humidity	84.9 \pm 6.0	95.7 \pm 2.1	55.4 \pm 1.9	56.1 \pm 1.8
Light (μ M \cdot m ² \cdot s ⁻¹)	None	None	Natural daylight + fluorescent 1.5 m beneath fixtures, 25 μ M \cdot m ² \cdot s ⁻¹	

* 28 June through 31 July, 2014

Experiment 1 In 2013, both ‘Sarah Bernhardt’ and ‘Duchess de Nemours’ responded positively to chilling temperatures (Figs 1a, c). ‘Sarah Bernhardt’ vase life increased linearly from an average of 8.4 days (no chilling) to 14.2 days with one week of chilling. This linear trend did not occur in 2014. In fact, for both cultivars, vase life was the same at all treatments including the control and for up to 14 days of chilling (Fig 1b, d).

The results for 2014 were puzzling because trials in previous years showed a positive effect of

chilling on vase life. Additionally, total vase life, especially for ‘Sarah Bernhardt’ showed vase life durations up to 2 times the national minimum of 7 days. (Holloway and Pietila 2014).



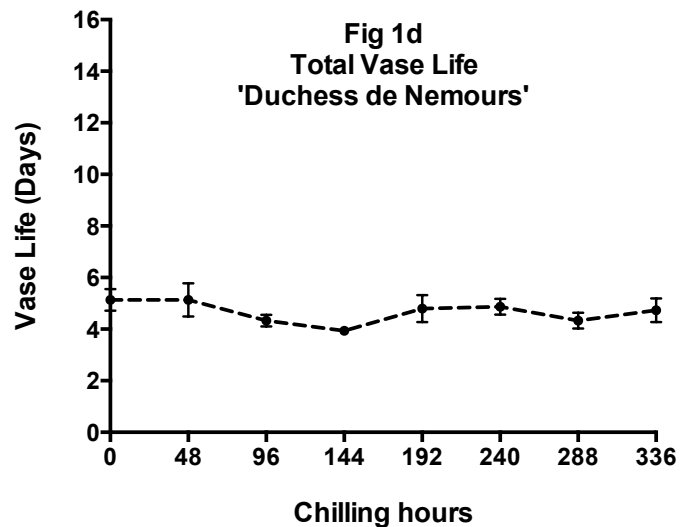
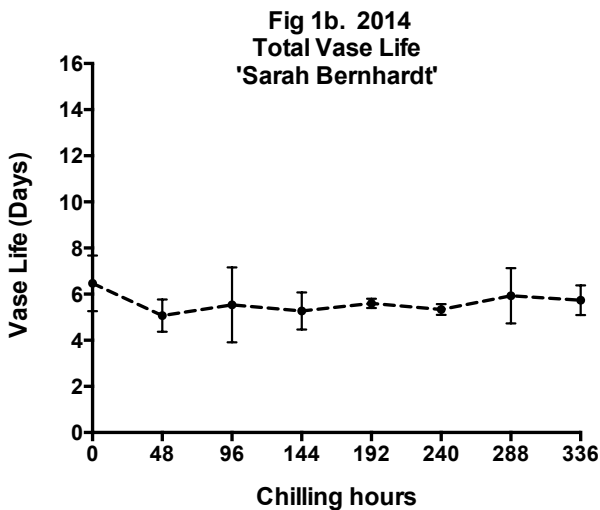
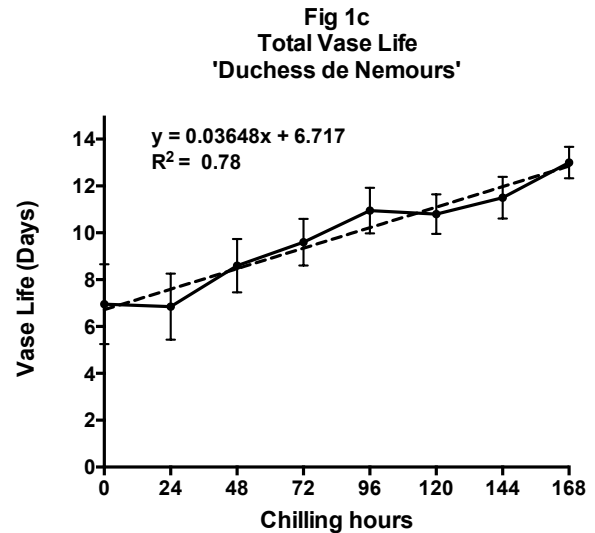
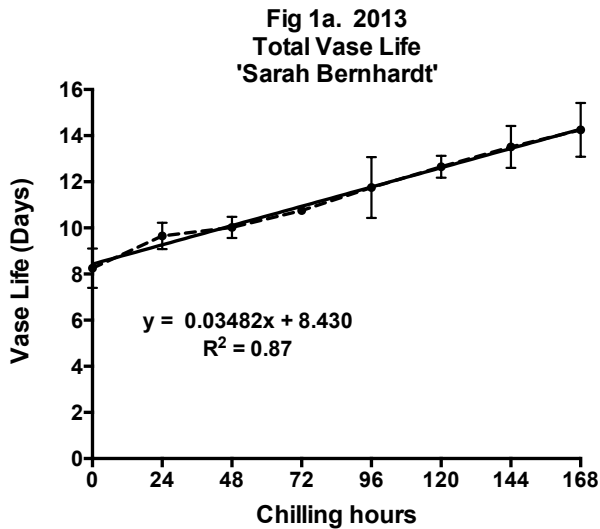
Ruth Osborne and Makenzie Stamey in the post harvest lab, 2014

Three factors might explain these results:

1. Environmental differences. The 2013 season was significantly hotter and drier early in the season during maximum peony growth than 2014 which was cold and wet beginning the third week of June with record rainfall in July (Table 1).
2. The refrigeration units where cut stems were held was a large laboratory cooler in 2013, and a cold storage Conex equipped with CoolBot® controls in 2014. (Table 2). Although temperatures were similar, relative humidity levels varied. This factor is unlikely because of results in experiment 4.

- Measurement error: different student interns were employed in the two years. Despite receiving the same training, post harvest handling differences might have occurred.

Figs. 1a- d. Vase life of 'Sarah Bernhardt' and 'Duchess de Nemours' peonies in 2013 (a, c) and 2014 (b, d) following different hours of post harvest chilling.



Experiment 2. Vase life and bud diameter did not differ significantly among early-, mid- and late-season harvests within each cultivar (Table 3). However, cultivars differed in total vase life ($P < .05$) and bud diameter ($P < .001$). We expected the bud diameter to decrease

over the season, but the selection was not random. We chose the largest buds for harvest on each date, and the size did not differ. The bud diameter was very consistent for each harvest date for 'Sarah Bernhardt' (very narrow standard deviations). Bud diameter for 'Duchess de Nemours' showed a much wider deviation from the mean indicating that bud size varies widely on all harvest dates even among the largest buds harvested.

Table 3 Vase life of Sarah Bernhardt and Duchess de Nemours peonies harvest at three different dates during the 2014 growing season.

Cultivar	Vase Life (Days \pm SD)*			Bud diameter (mm \pm SD)***		
	Early (1 July)	Mid (8 July)	Late (15 July)	Early (1 July)	Mid (8 July)	Late (15 July)
Sarah Bernhardt**	6.4 \pm 1.2	5.5 \pm 1.6	6.1 \pm 1.0	44.6 \pm 0.5	43.7 \pm 1.9	44.3 \pm 1.3
Duchess de Nemours	5.1 \pm 0.4	5.0 \pm 0.4	4.7 \pm 0.4	35.0 \pm 4.0	37.2 \pm 3.0	33.6 \pm 3.5

* Followed 7 days of chilling at 34F, 3 replicates of 6 peony stems each.

** Cultivars differed significantly for total vase life ($P < .05$), no difference in harvest dates

***Cultivars were highly significantly different for bud diameter ($P < .001$) but not for harvest date

Experiment 3. Of the 110 cultivars at the UAF Georgeson Botanical Garden, 68 cultivars produced sufficient flowers for vase life analysis in 2013 and 2014. Vase life for all cultivars in 2014 ranged from 4 days to 9 days (mean 6.0 ± 1.0 days). In 2013, vase life averaged 8.6 ± 2.7 days (range 4 - 14 days) (Figs. 2a - f). Not only was the average vase life more than 2 days longer for flowers in 2013, the variation among cultivars as reflected in the standard deviation was greater. Both cultivar and year effects were highly significant ($P < .001$), and there was a significant interaction between years and cultivars. These variables are not independent. We expected cultivars to differ significantly in vase life, but the difference between years was unexpected.

Vase life for 2014 was significantly lower for most cultivars than 2013. In 2013, more than 70 percent of the cultivars showed an average vase life of 7 days or more. However, in 2014, only 24 percent of the cultivars had a similar average vase life (Table 4). In 2013, the four main classifications of peonies grown at the botanical garden (semi-double, Japanese, bomb and full double) showed similar average vase life ranging from 5 days to 17 days. The bomb classification showed a slightly lower vase life, but only three cultivars were tested as compared to 41 cultivars for full doubles. The major classification that showed a vase life consistently less than 7 days was the Intersectional hybrids. Because different cold storage units were used, the methods were not exactly equal for both testing years.

Fig 2a. Total Vase Life (2013, 2014)

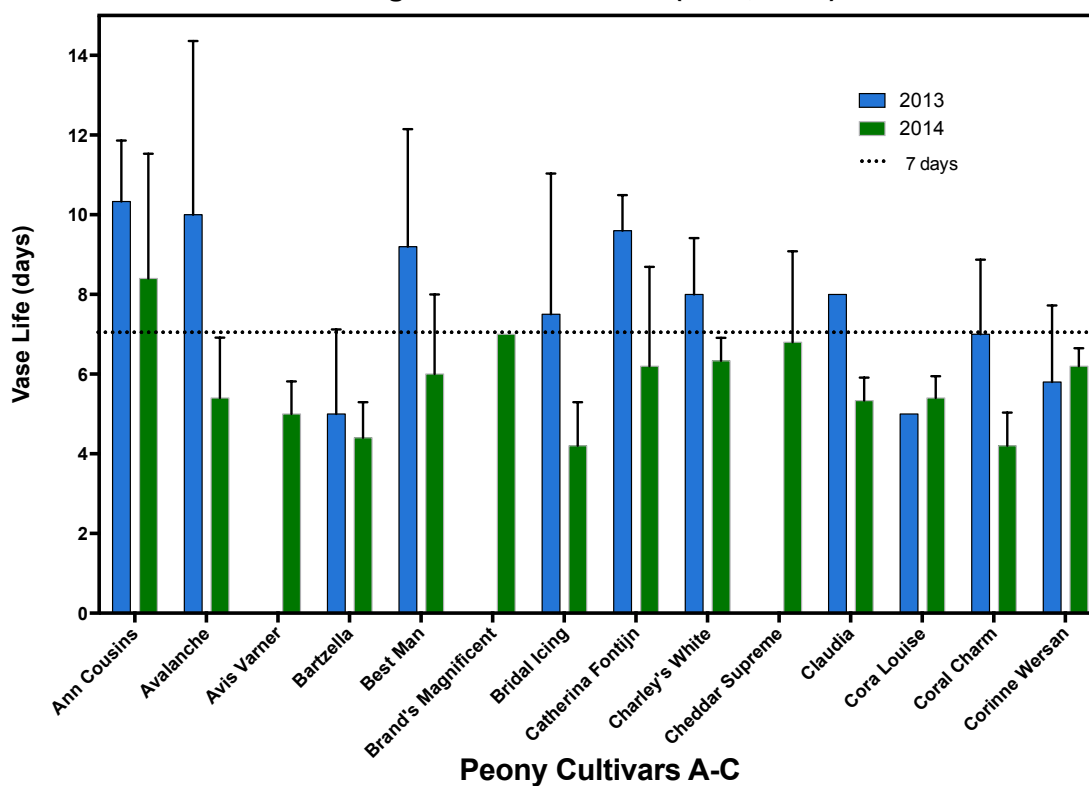


Fig 2b. Total Vase Life (2013, 2014)

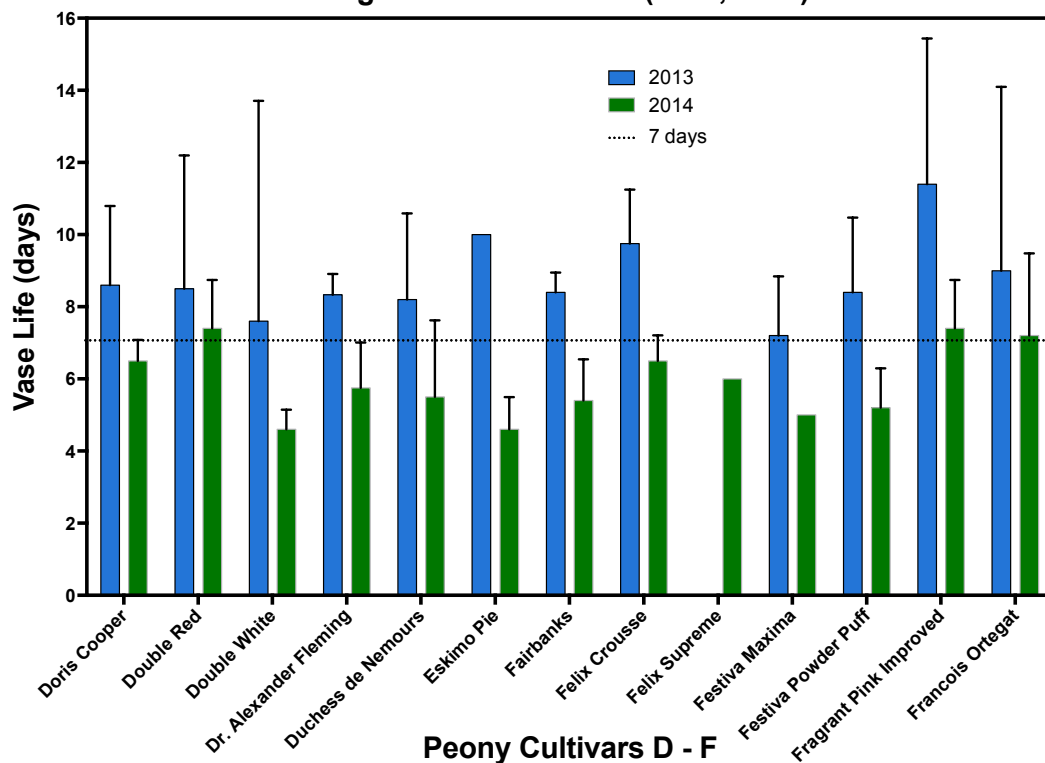


Fig 2c. Total Vase Life (2013, 2014)

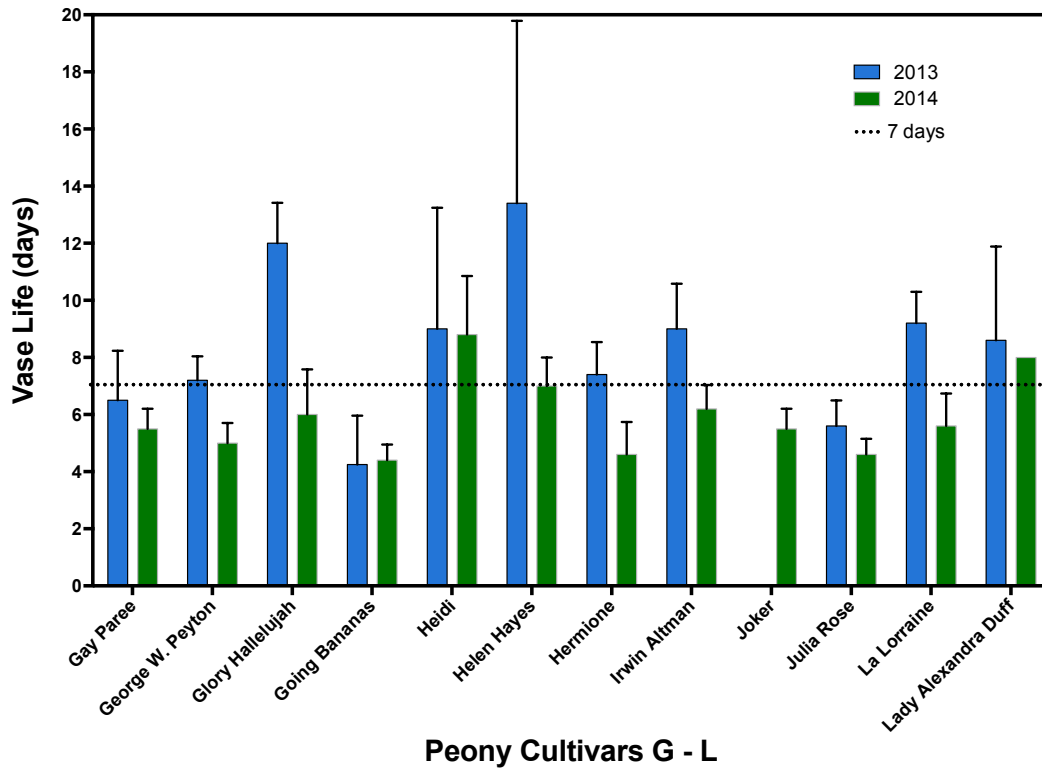


Fig 2d. Total Vase Life (2013, 2014)

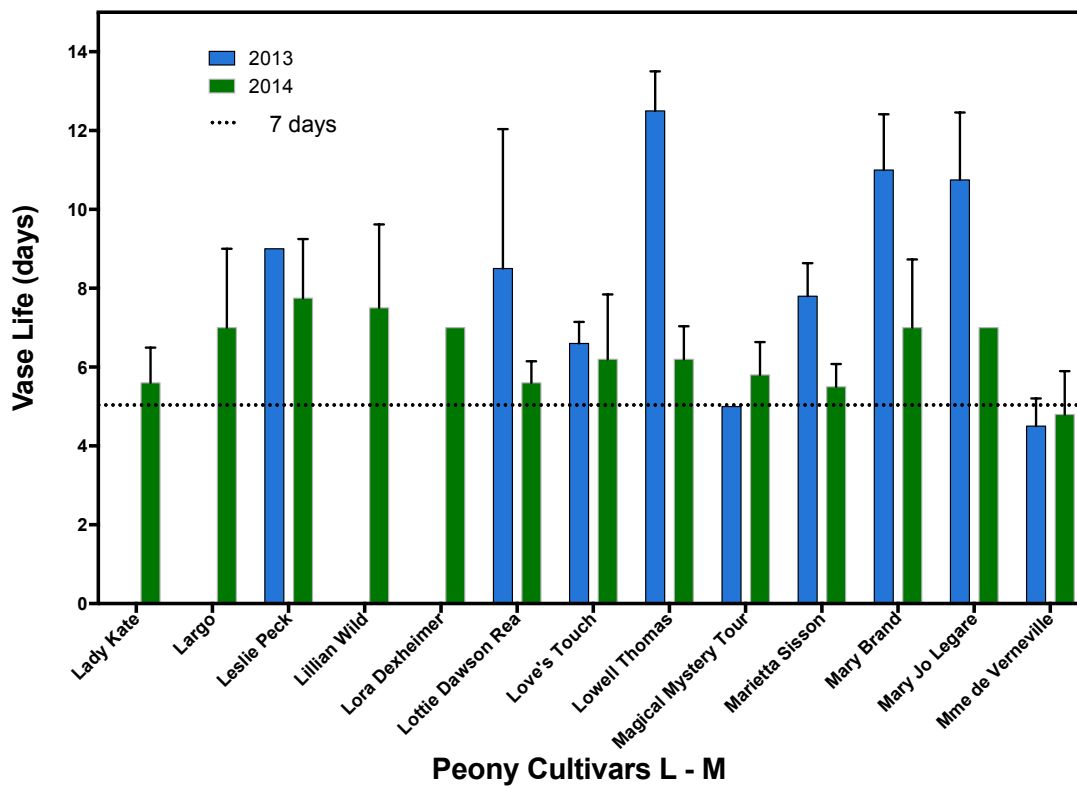


Fig 2e. Total Vase Life (2013, 2014)

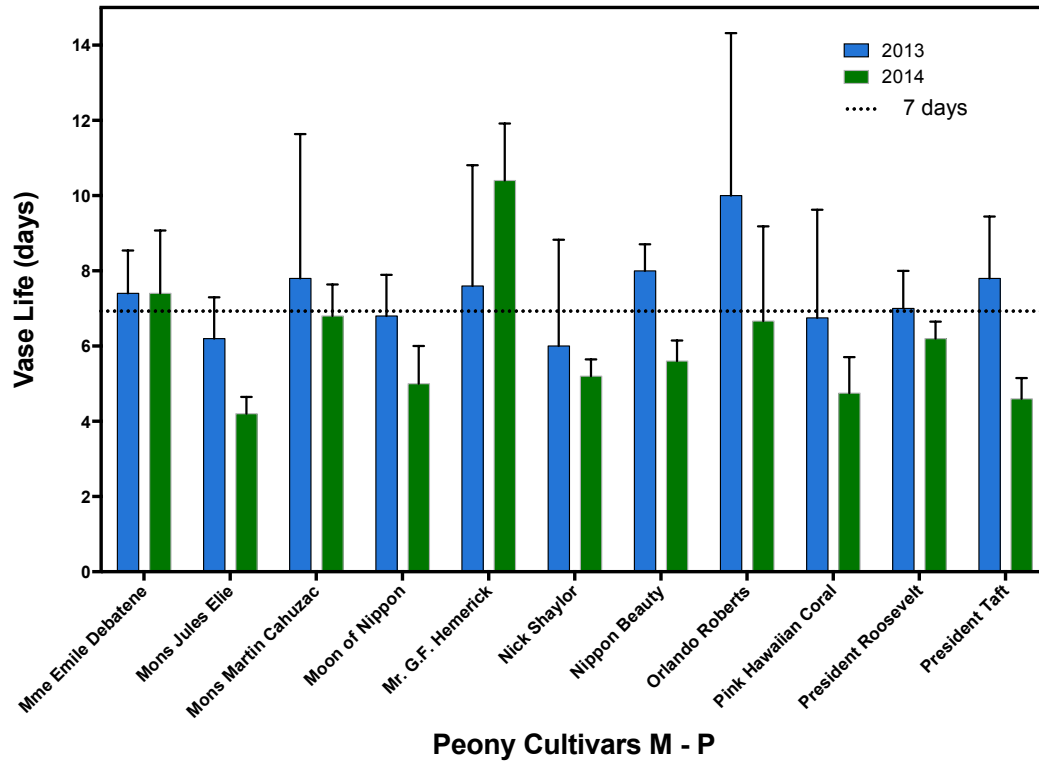


Fig 2f. Total Vase Life (2013, 2014)

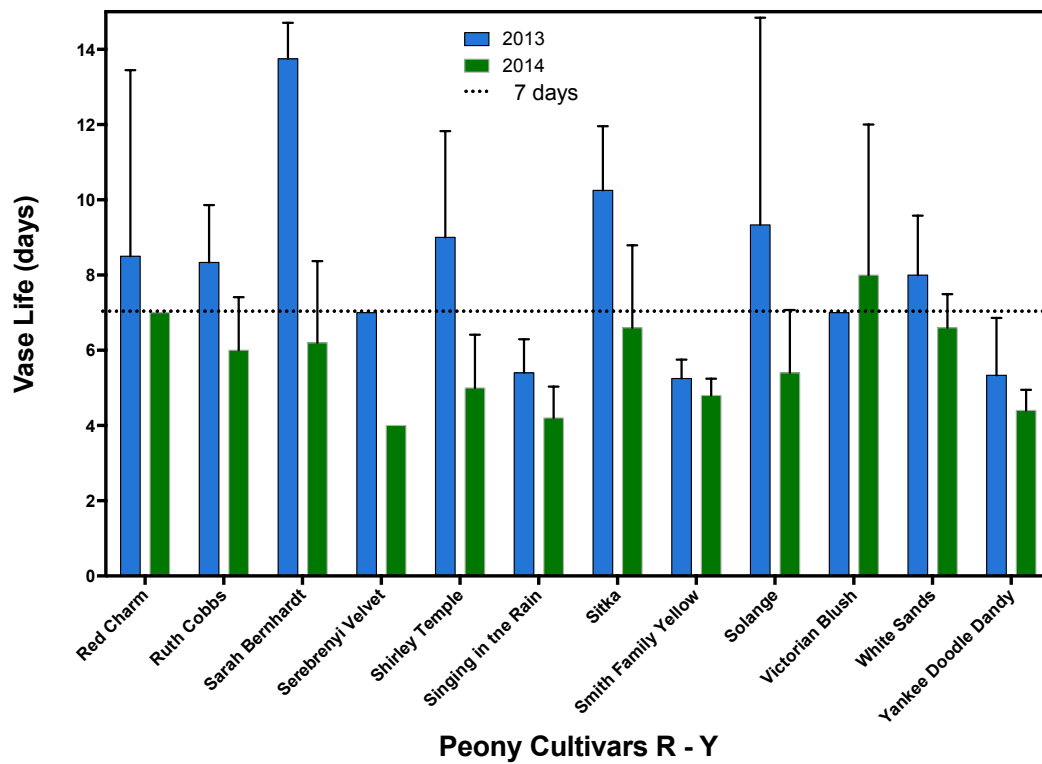


Table 4. Vase life for peony flower classes.

Cultivars and Classification	Cultivars with > 7 days average vase life (%*)		
	2013	2014	
All cultivars	71	26	
Japanese n= 10	90	30	
Semi Double 6	50	33	
Bomb 3	100	33	
Full Double 41	90	24	
Intersectional (ITOH) single 1	0	0	
Intersectional semi-double 5	0	0	
Intersectional double 2	0	0	
	Total vase life Days (mean) [min – max]		
Japanese n= 10	9.8 [6 - 10]	6.7 + 1.2 [5 – 9]	
Semi Double 6	8.8 [6 – 15]	6.0 + 1.1 4 – 7]	
Bomb 3	8.0 ± 0.5 [7.5 – 8.5]	7.0	
Full Double 41	9.4 ± 2.9 [5 – 17]	6.0 ± 1.0 [4 – 8]	
Intersectional (ITOH) single 1	4.0	4.0	
Intersectional semi-double 5	5.3 ± 0.2 [5 – 5.6]	4.2 ± 0.4 [4 – 5]	
Intersectional double 2	5.0	4.5 ± 0.7 [4 – 5]	

*Total n = 68, only included cultivars with harvestable blooms both in 2013 and 2014

Experiment 4

Vase life trials among commercial Alaska growers. We worked with two pack houses, North Pole Peonies and Polar Peonies to obtain samples of ‘Sarah Bernhardt’ peonies for the commercial grower trials. North Pole Peonies pack house did not submit any samples from growers because of high levels of bud blast throughout the Interior. Polar peonies submitted samples from three farms: Springerhill Farm, Nenana, Little Plum Farm, Fairbanks and Georgeson Botanical Garden. The farms did not differ significantly in vase life for the samples submitted. The average vase life for all farms was 4.8 ± 1.2 total days. The number of farms completing this project were too small to show regional differences. Many farms had significant issues with bud blast (attributed to winterkill and *Lygus* bugs), and could not submit samples.

One interesting note from this study is that the cold storage of these small samples occurred at the pack house cooler, not the University cooler. The poor vase life seems to be region wide, in which case the cause for the overwhelmingly poor vase life in 2014 appears to be environmental or post harvest handling difference and not related to the coolers as speculated in Experiment 1.



‘Sarah Bernhardt’ peonies tagged for vase life studies

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Postharvest Handling Methods for Enhanced Competitiveness of Fresh Cut Peonies

Part 2. Effect of Boron and Calcium Sprays on Stem Strength of Peonies

Mingchu Zhang and Robert Van Veldhuizen

Introduction

The peony flower produced in Alaska is large in size. As such, the stem strength of the harvested cut flower can affect the vase life of peony. Research conducted in Chile show that spraying a calcium (10%) and boron based solution to peony cut flowers prior to harvest can increase stem strength (measured as curvature), stem weight and increase in vase time (Nelson et al., 2012). In China, spraying 4% calcium on herbaceous peony shows an increase in mechanical strength (Li et al., 2012). This enhanced mechanical stem strength probably is gained through an increase of the fraction of cell wall, endogenous calcium and pectin concentration. To increase Alaska peony competitiveness in the market, it is necessary to know if a calcium based or calcium and boron based spray solution prior to harvest can increase the postharvest quality of the Alaska peony flower.

Herbaceous peonies have a short growing season in Alaska (about 3 months). As such, they have a fast growth rate of the above ground biomass. In addition, the relative humidity in Alaska is low, indicating that a spray solution can be evaporated quickly before it is imbibed by the stems after spraying. Therefore, the designed solution for spraying should have a relatively longer residence time on the plant tissue to allow for more complete imbibition. Also, considering the availability of water in the rural communities, well water should be also taken into consideration. The objectives of the research was to 1) develop an optimal solution for a spray; 2) determine the stem diameter and strength as affected by the spray; and 3) determine the calcium and boron uptake by stems after spraying.

Methods and materials

A laboratory experiment was conducted in the Soils Laboratory of SNRE, UAF. A variety of chemicals were evaluated for their suitability as a spray agent. Two criteria were used for evaluation, 1) the solution should contain an organic compound so that it can have a prolonged resident time on tissue surface, and 2) the pH should not be extreme, either acidic or alkaline. After selecting the appropriate chemical compounds, the final spray solutions contained 5% Ca + 0.5% B + 0.1% K and 10% Ca + 0.5% B + 0.1% K. Both solutions had an approximate pH around pH 6.

A field experiment was conducted by spraying the solutions in the AFES research peony field mixed up in well water and in distilled water, respectively. The spray treatments were: 1) 5% Ca + 0.5% B + 0.1% K in distilled water, 2) 5% Ca + 0.5% B + 0.1% K in well water, 3) 10% Ca + 0.5% B + 0.1% K in well water, 4) 10% Ca + 0.5% B + 0.1% K in distilled water, and 5) no spray (control). Each treatment consisted of 32 plants, with the test cultivar being 'Sarah Bernhardt'. Two sprayings were

conducted, one at the two weeks prior to hard bud stage (Stage 2), and the other at the hard bud stage (Plate 1). Six stems were randomly taken for testing at the regular flower cut time. Each test stem was cut right at the first leaf below the flower bud. The stems were measured for their length, diameter, strength, and then dried and ground for laboratory determination of Ca, B and K uptake. This year, peonies in interior Alaska all suffered from significant bud blast. As such, the results may not truly reflect the impact of the treatment due to irregularity of plant growth.

The instrument for measuring stem curvature and stem strength was developed with the help from faculties in the College of Engineering and Mines, UAF. The measurement apparatus consisted of a load cell and a Linear Variable Differential Transformation (LVDT) instrument connected to a continuous data logger, battery, and holding clamps for the peony stem (Plates 2, 3, 4). The apparatus was calibrated for different masses of the forces that can cause the curvature and eventual breakage of a peony stem.



Plate 1. Spraying a treatment on peonies at the Fairbanks Experiment Farm, Agriculture and Forest Experimental Station, University of Alaska Fairbanks.

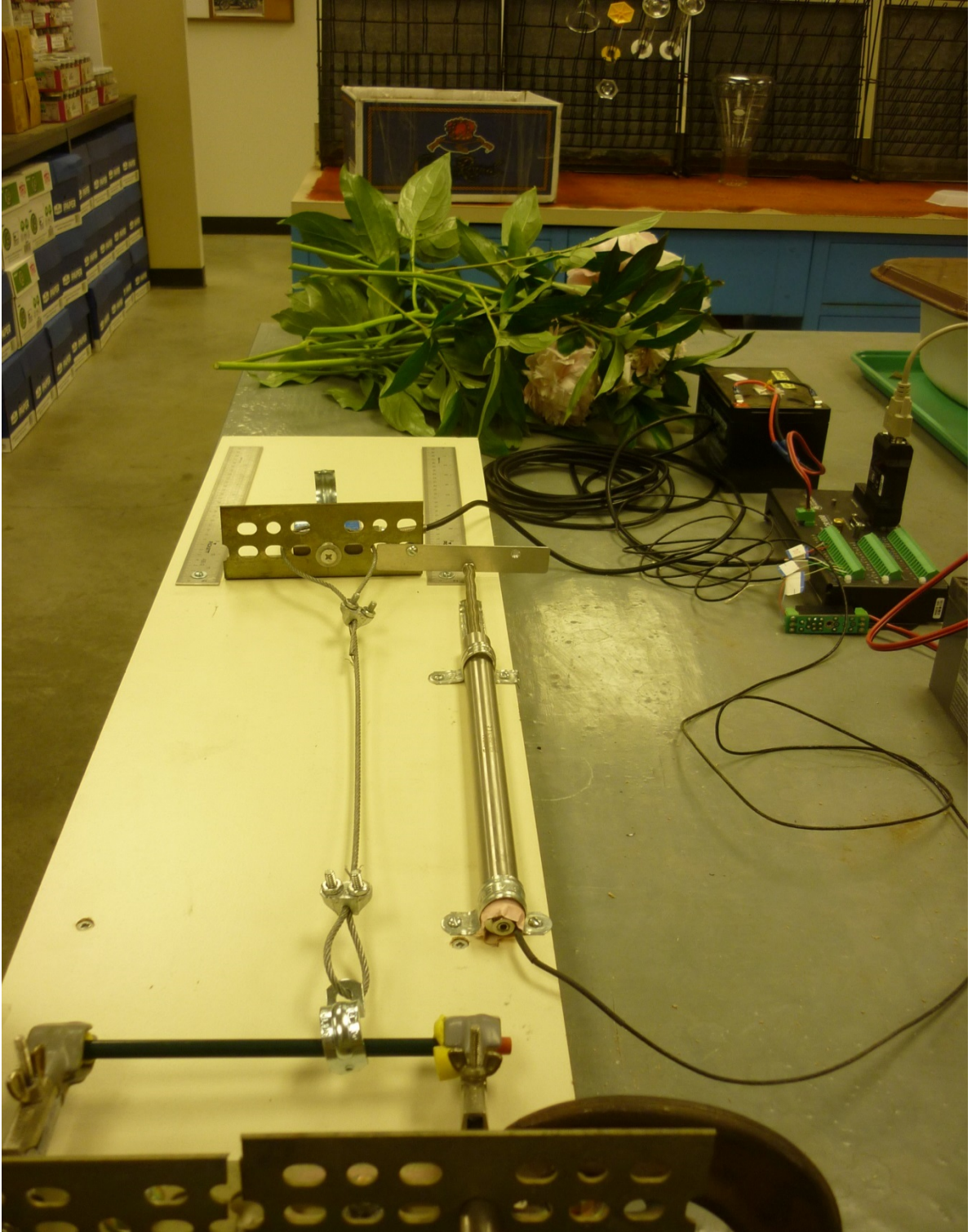


Plate 3. Test apparatus for stem curvature and strength, load cell attached to the bottom plate, LVDT attached on the right, and continuous data logger on the table (far right).

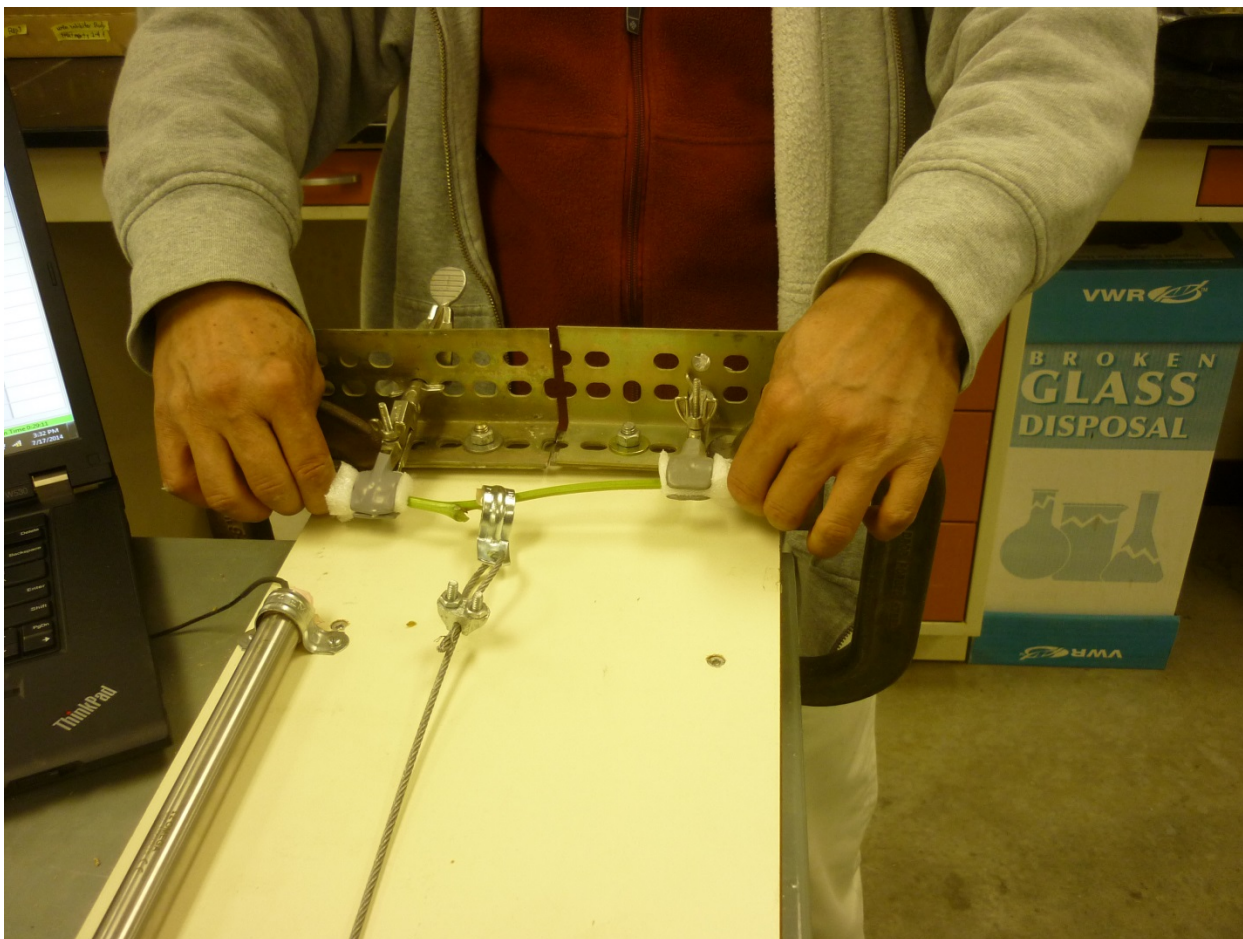


Plate 4. Testing for stem strength and curvature.

Results

The stem diameter tended to be larger in the control treatment (Table 1). The no effect from spraying perhaps was caused by the irregular growth of the plants due to the severe bud blast this year. However, the nutrient concentration in the stem tissue showed a difference among treatments (Tables 2, 3). There was a marginal difference for potassium (K) concentration in stem tissue, but no trend can be followed (Table 2). For micronutrients, on the other hand, there was a significant difference among the treatment for boron (B), but not for calcium (Ca) (Tables 2, 3). In the spray solutions there was 10% Ca and 0.5% B. Calcium concentrations in stem tissue appeared to be not different among treatments, but the boron concentration was higher for the spray treatments than the control (no spray) (Table 3). The sources of water (well vs. distilled water) for making the solutions were not contributing to B uptake by plants (Table 3). In addition, manganese (Mn) concentration in the tissues was different among treatments (Table 3). Well water was used for Treatment 2 and 3, and distilled water was used for Treatments 1 and 4. Manganese concentration in Treatment 1 and 4 tended to be higher than that in the Treatment 2 and 3. Therefore, it seemed that source of water did have some impact on

Mn uptake. Manganese is one of the essential plant nutrients participating in many biological processes in plant (e.g. photosynthesis) (Millaleo et al., 2010). It was not clear why solution made of distilled water enhanced uptake of Mn in plant tissue.

The newly assembled instrument was calibrated for the stem strength and curvature (or bending distance prior to break) test (Plate 5). The variation of forces and their corresponding voltages were correlated significantly ($r^2 = 0.999$, $p < 0.01$) (Fig. 1). The variation of distances and differential voltage also correlated significantly ($r^2 = 1$, $p < 0.05$) (Fig. 2). These two calibrations set up the basis for determining the force and the bending distance to break peony stems. In the stem strength test, voltage changes were recorded in the data logger connected to the load cell and LVDT instruments, and then calculated for force and distance from the regression equations in Fig. 1 and Fig. 2.

The forces required to break stems did vary from stem to stem (Fig. 3). The higher the peak in the Fig.3 indicated the larger force that was required to break the stem since there was a positive relation between the voltage and force (Fig. 1). However, the corresponding bending distance prior to breaking appeared to have less variation compared to the force (Fig. 4). There was a negative relation between the distance and voltage, therefore, the shorter the peak the longer the distance prior to breaking. It appeared that there was no relation between the amount of force required to break stems and the bending distance at stem breaking (Fig. 5). Scatter plots showed that the relations between stem diameters and stem breaking force (Fig. 6) and between stem diameter and the distance (Fig. 7) were not obvious.

Weather conditions in the summer of 2014 were not favorable for peony growth. There was a prolonged cool and wet summer during the flower production period in June and July. In addition, there was an unknown variable that caused the abortion of flower buds in many peony plants. All of these can affect the absorption of sprayed solutions by peony plants. As such, peony stem diameters seemed to not positively respond to the spray treatments (Table 1). Also, the stem strength and stem diameter were not correlated. For the stem strength and bending distance determination, the challenge still existed for the device that holds the stem for the determination even after many improvements. Stems in the holding device tended to slide out if a moderate grabbing force was used. On the other hand, the stem ends being held were broken when a strong grabbing force was used. This challenge may not affect the forces to break the stems, but it certainly affected the bending distance prior to stem breaking. Future improvements are needed for a more accurate determination of bending distance.

In conclusion, peony absorbed B but not Ca and K from the solutions sprayed on peony plants prior to flower cut, indicating spraying might be an effective way for applying B to peony plants. The spray solutions didn't affect the stem diameter in 2014, which might be caused by abnormal weather in the summer of 2014 or the unknown variable that caused abortion of peony flowers. Therefore, to verify the impact of the spray solution on stem strength, further evaluation on the impact of sprayed solution on peonies is needed. The newly developed device can detect the forces required to break peony stems, but still fell in short to accurately determine the bending distance prior to stem breaking. Further improvements are needed to make the holding device more accountable to properly hold peony stems for testing.

Table 1. Stem length (from bud to first true leaf), and stem diameters from the spray treatments.

Treatment ^a	Stem Length (mm)	Stem diameter (mm)		
		Base	30-cm ^b	Top
1	327.3	5.6	5.5	3.3
2	402.7	7.3	6.5	4.5
3	410.7	7.0	6.6	4.5
4	357.0	6.7	6.5	4.4
5	473.8	7.4	6.6	4.7
Prob. (F test)	0.10	0.05	0.07	0.12
LSD (0.05)	111.0	1.2	0.8	not significant

^aTreatment: 1) 5% Ca + 0.5% B + 0.1% K in distilled water, 2) 5% Ca + 0.5% B + 0.1% K in well water, 3) 10% Ca + 0.5% B + 0.1% K in well water, 4) 10% Ca + 0.5% B + 0.1% K in distilled water, and 5) no spray (control). ^b 30 cm below the bud.

Table 2. N, P, K, Ca and Mg concentration in stem tissue of treated and non-treated stems harvested in July 30, 2014.

Treatment ^a	N%	P%	K%	Ca%	Mg%
1	1.31	0.13	0.28	1.40	0.42
2	1.54	0.15	0.40	1.43	0.36
3	1.32	0.14	0.25	1.40	0.43
4	1.39	0.14	0.29	1.34	0.38
5	1.37	0.15	0.41	1.29	0.35
Prob. (F test)	0.11	0.58	0.02	0.89	0.20
LSD (0.05)	NS	NS	0.11	NS	NS

^aTreatment: 1) 5% Ca + 0.5% B + 0.1% K in distilled water, 2) 5% Ca + 0.5% B + 0.1% K in well water, 3) 10% Ca + 0.5% B + 0.1% K in well water, 4) 10% Ca + 0.5% B + 0.1% K in distilled water, and 5) no spray (control).

Table 3. Cu, Zn, Mn, Fe, Cu, and B concentration in stem tissue of treated and non-treated stems harvested in July 30, 2014.

Treatment ^a	Cu	Zn	Mn	Fe	B
	ppm				
1	4.33	14.17	15.92	58.27	39.15
2	4.70	15.88	12.45	43.55	39.73
3	4.42	15.03	11.60	36.30	40.75
4	4.30	14.48	14.05	58.22	50.83
5	4.40	16.27	11.67	49.25	17.63
Prob. (F test)	0.50	0.60	0.03	0.44	0.0001
LSD (0.05)	NS	NS	2.93	NS	11.05

^aTreatment: 1) 5% Ca + 0.5% B + 0.1% K in distilled water, 2) 5% Ca + 0.5% B + 0.1% K in well water, 3) 10% Ca + 0.5% B + 0.1% K in well water, 4) 10% Ca + 0.5% B + 0.1% K in distilled water, and 5) no spray (control).



Plate 5. Peony stem was broken after imposed certain force with the force at the point of stem breaking recorded in the data logger.

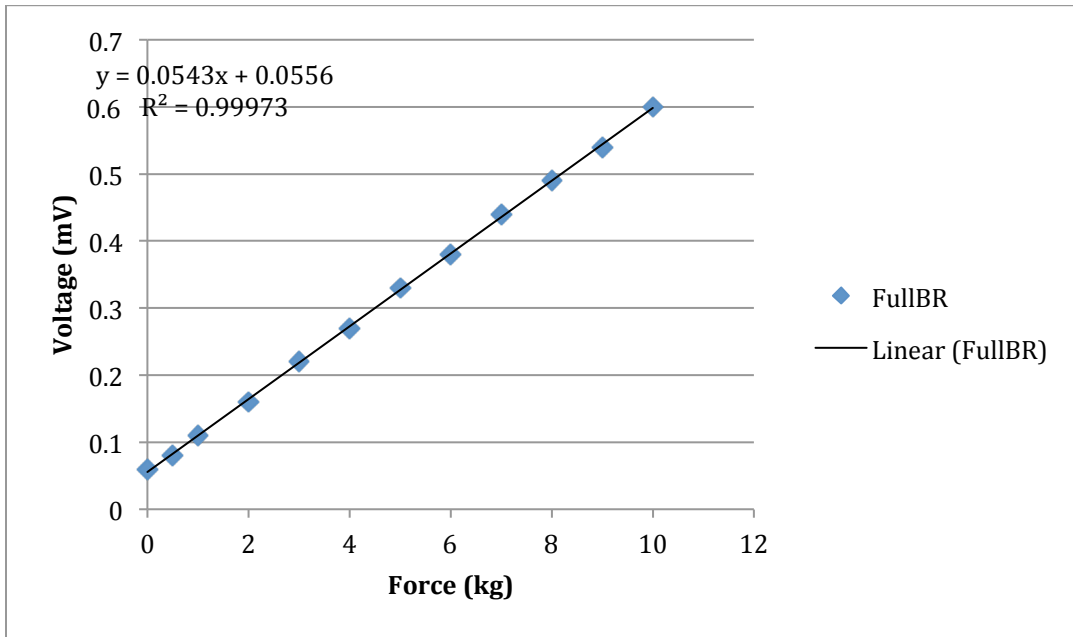


Fig. 1. Calibration of forces for the load cell.

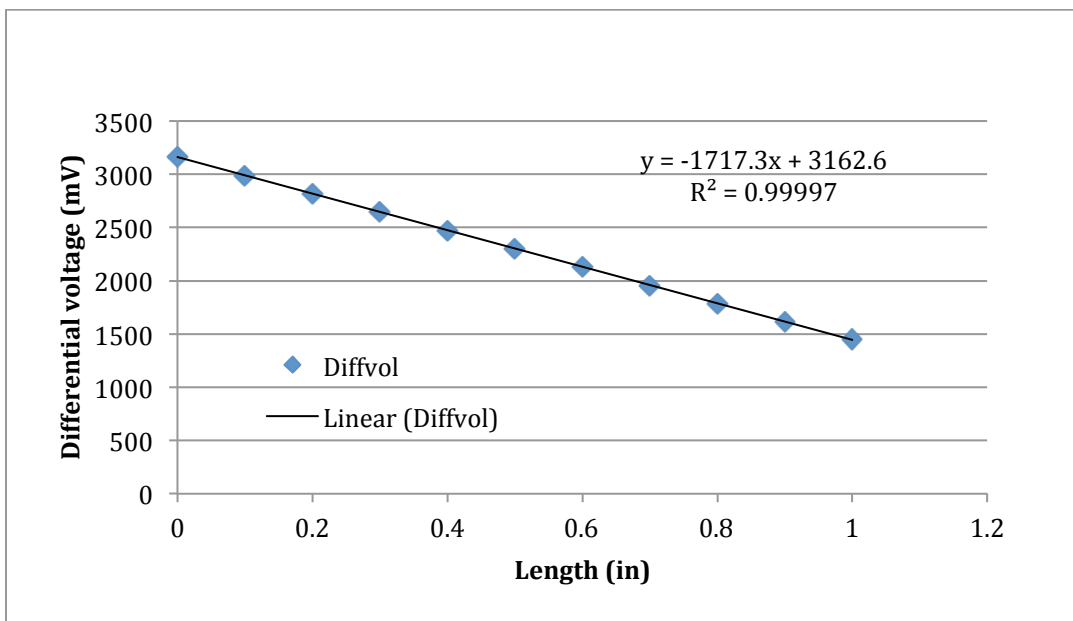


Fig. 2 Calibration of linear variable differential transformation (LVDT).

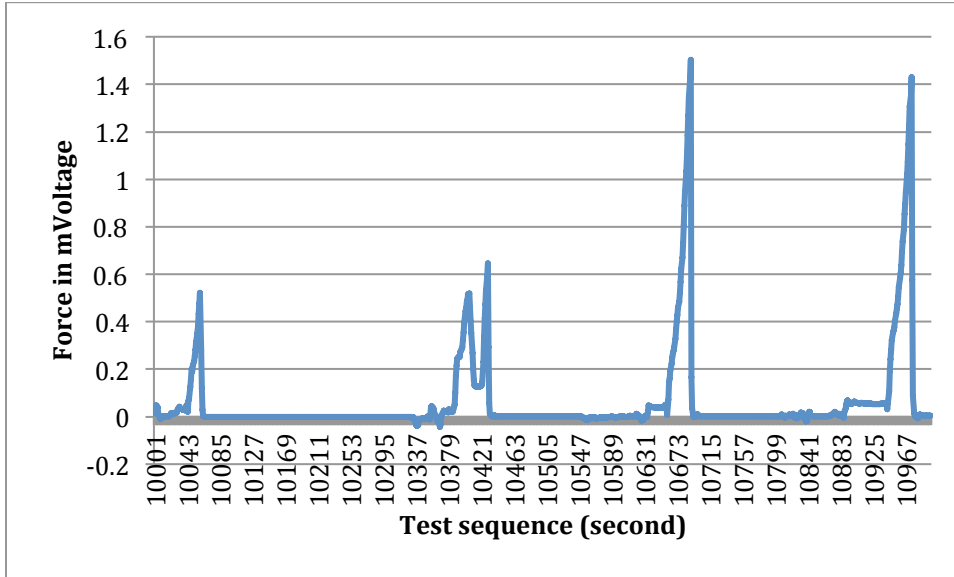


Fig. 3. Example of test for breaking force for peony stems. The higher the peak, the larger the force is required to break the stem.

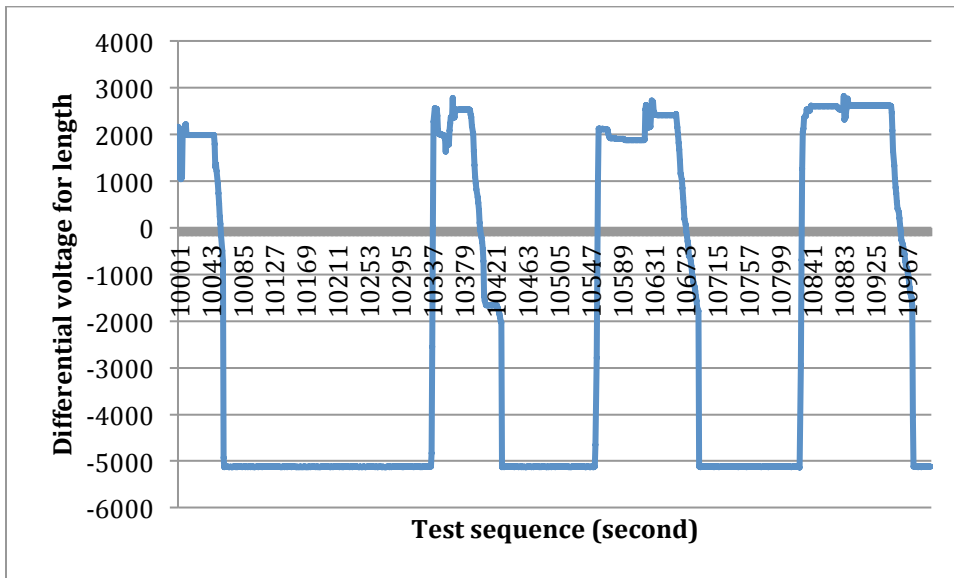


Fig. 4. Example of test for bending distance from which stem was broken. The lower the peak, the more the bending of stem can bear.

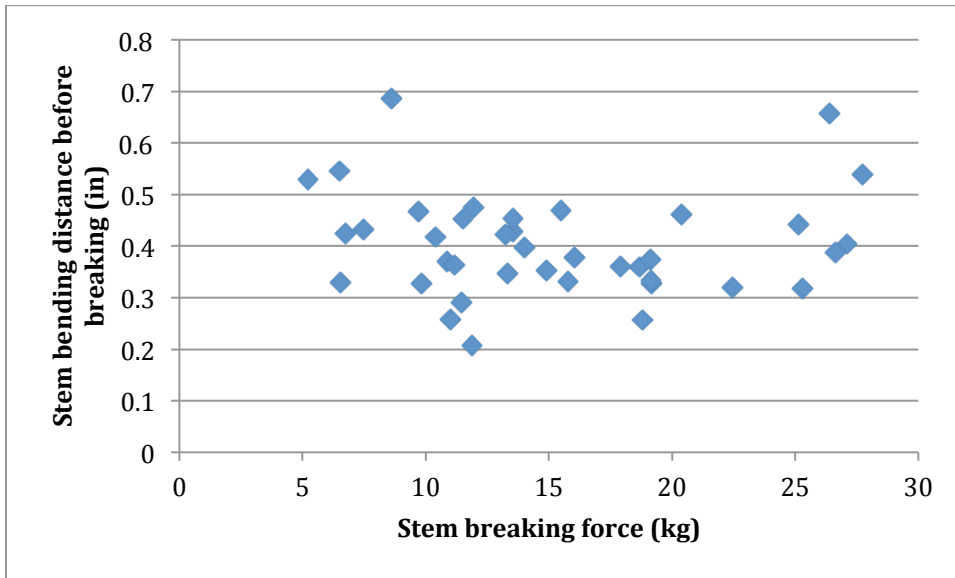


Fig. 5. Relationship between bending forces and bending distances of stems.

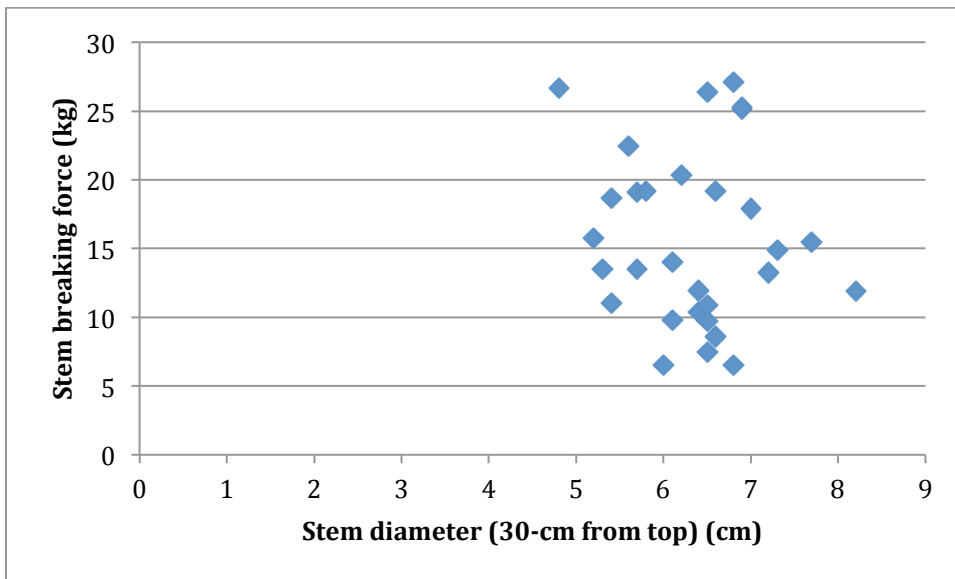


Fig. 6. Relationship between stem breaking forces and stem diameters (30-cm the top).

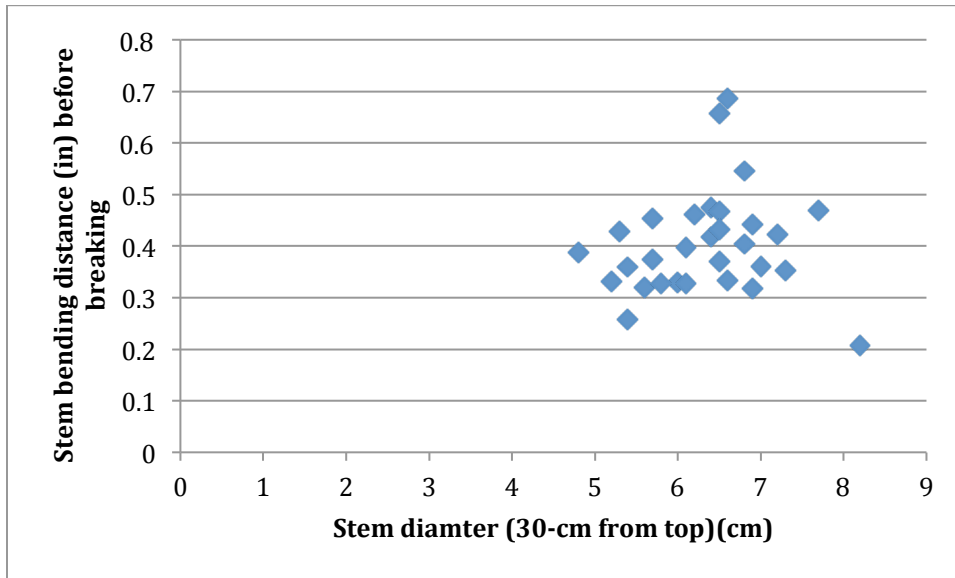


Fig. 7. Relationship between stem bending distances before breaking and stem diameters (30-cm from top).

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