THE EFFECTS OF SPENT FLOWER REMOVAL ON REBLOOMING AND BRANCHING ARCHITECTURE AND THE CHARACTERIZATION OF FLORAL HEAT TOLERANCE OF GARDEN ROSES

A Thesis

by

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ABSTRACT

Spent flower removal is commonly practiced on remontant garden roses as a landscape management tool to hasten rebloom. To study the effects of spent flower removal on the reblooming and branching architecture of garden roses, four Shrub rose cultivars were established in the field in February 2019 and treatments were started in June 2019 at Somerville and Overton with the same treatments and controls in each cultivar. Spent flower removal had no effect on the days to rebloom between flushes of flowering. 'Belinda's Dream' had the longest reblooming period. The current season growth and primary shoot number were not affected by spent flower removal. Plants in Somerville exhibited a higher number of secondary and tertiary shoots than in Overton regardless of cultivar and more quaternary shoots on some cultivars than those in Overton. This is likely attributable to the longer growing season in Somerville than in Overton.

An important aspect of heat tolerance of ornamental plants is the response of the flowers to high temperature. Commercial garden rose cultivars with buds 4 mm in diameter were exposed to temperatures of 36, 40, or 44 ˚C for durations of 1, 3, or 5 h in factorial combination in a heat chamber and compared to untreated controls to determine the effects of heat on floral parameters including petal number, flower diameter and flower dry weight when flowers were fully open. The number of treatments different from the control determined using Dunnett's test and the parameters affected by the temperature × duration factors as determined by ANOVA were used to categorize the cultivars studied.

Dry weight was the most sensitive parameter measured. ‘CHEwnicebell’ and ‘ZLEMarianne Yoshida’ were categorized as Heat Sensitive cultivars, ‘Winnipeg Parks’ was categorized as Moderately Heat Susceptible. ‘Morden Blush’, ‘Meipeporia’ and ‘RADrazz’ was considered as Moderately Heat Tolerant cultivars. ‘RADtko’ and ‘RIPhud’ were not affected by the heat treatments and were categorized as Heat Tolerant cultivars. Exposure of plants with buds 4 mm in diameter to 44 ˚C for 3 or 5h was the most effective treatment for determining floral heat tolerance for the cultivars studied.

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Contributors

This work was supervised by a thesis committee consisting of Dr. H. Brent Pemberton as advisor, Dr. David Byrne as co-advisor, Dr. Genhua Niu of the Department of Horticulture and Dr. Patricia Klein of the Department of Horticulture and a member of the Interdepartmental Molecular and Environmental Plant Sciences program and a member of the Institute for Plant Genomics and Biotechnology.

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CHAPTER I

INTRODUCTION

Roses and its importance

Rose belongs to the genus *Rosa* in the *Rosaceae* that includes about 200 species divided into four subgenera. There are more than 30,000 cultivars of roses and they are widely used as ornamental plants, in the cosmetic and food industries, and medicinal areas.

Rose is one of the most popular flowers because of its recurrent flowering and its vast diversity of flower and plant forms. The wholesale market of garden roses in the United States was valued at $203.5 million in 2014 (USDA, 2018). However, wholesale value has decreased over time, the cost of producing garden rose plants has been increasing, and both biotic and abiotic stresses could lead to higher costs for maintaining the yield of rose plants (Byrne et al., 2010; Hutton, 2012; Pemberton and Karlik, 2015). Thus, the understanding of rose plant growth and the effects of the ambient environment on roses are necessary for the production and the breeding of improved garden roses in the future.

Plant architecture and research progress on roses

The study of plant architecture is derived from earlier works on the morphological and topological patterns found in tropical plants (Halle and Oldeman, 1970). Plant architecture determines the shape of plants, flower productivity, and ultimately its ornamental value (Crespel et al., 2013). The idea of topology (which breaks the plant

into small pieces at different scales on axis and metamers) and geometry (the relationship of succession and branching) are utilized in the description of plant architecture types (Morel et al., 2009).

Shoot growth and branching habits vary among different cultivars in the same species. The activity of branching is considered the growth stimulation that alters plant architecture (Bell et al., 1979). Manipulating the plant shape affects photosynthesis absorption by altering light in the canopy of plants (Sarlikioti et al., 2011) and changes the organic mass in total. Plants with different growth habits may have a variable response to the same pruning method. Rose plants that were managed to have a denser canopy with more bud breaks yielded more shoots, but had smaller flowers and more blind shoots than those managed to have a less dense canopy when considering the growth harvested for cut flowers (Kool et al., 1997). By removing the apical part of the plants, the hormone content and movement is a factor that influences the growth condition of plants. The involvement of a class of auxins, cytokines, and strigolactones, which are communication chemicals from root exudates, alter the growth of shoot branch development (Umehara et al., 2008).

In the study of the architecture of rose bushes, the variables include the number and length of the axis and orders. Thus, rose primary shoots and levels of branches (i.e., secondary shoots as order 2 and tertiary shoots as order 3) were measured and related to the plant shape (Crespel et al., 2013). The visual pattern of shoot growth influences the quality of landscape value. The number of primary shoots and the number of further developed secondary and tertiary shoots are important factors in selection (Wu X. et al.,

2019a). Garden rose plant architecture was studied on two garden rose cultivars, ‘RADrazz’ and ‘Meiratcan’, and the study quantified the plant axes from top projection of the whole canopy and the growth of internodes, nodes and auxiliary buds were used as components to develop the growth simulation model. Plant architecture components were also evaluated for heritability (Kawamura et al., 2015; Wu X. et al., 2019b).

Pruning effects on plants

Genetic factors, the environment (temperature, rainfall, light, and soil), biotic factors (insects and diseases), and horticultural manipulation (pruning, pinching, and growth regulators) influence the pattern of shoot growth and plant architecture (Barthélémy and Caraglio, 2007). Pruning plants is a practical technique for maintaining plant shape. Pruning not only shapes the ornamental plants but is also important for plant development (Särkkä and Eriksson, 2003). Cutting off the upper part of a shoot stimulates the movement of carbohydrates and removes the apical dominance effect of the shoot tip (Calatayud et al., 2007). Pruning alters the metabolic sink and increases photosynthetic activity. Pruning roses tends to promote more carbohydrate transfer from the lower parts of the plant to new flowering shoots (Calatayud et al., 2007).

An important topic for researchers to explore is how pruning affects plant architecture and the production of more floral shoots. One type of plant pruning of rose cut flower types is described as a de-shooting process which boosted plant growth and development including the rose root system (Zieslin and Mor, 1981). In a mild winter climate field study with a year-around repeat flowering essential oil rose cultivar (hybrid

tea rose ‘Eiffel Tower’), heavy autumn pruning (plants pruned leaving 5 primary shoots and cut at 25 cm height) increased shoot length compared to non-pruned plants, and light autumn pruning (plants pruned leaving the healthy secondary shoots on each plant and cut at 75 cm height) increased flowers per plant when compared to non-pruned plants when flowering shoots were harvested and compared during the following winter flowering period (Hassanein, 2010).

Pruning is used to manipulate rose plant growth to encourage more flower production for gardeners. Spent flower removal often referred to as “Deadheading” is one of the common pruning methods used for garden roses as it reduces the risk of diseases from spent flowers and is commonly assumed to hasten rebloom on remontant rose cultivars, especially on hybrid tea and floribunda types (Hessayon, 1981; Scanniello and Bayard, 1990). Deadheading is described as cutting off the spent flower at the third or fourth leaf from below the flower which is usually the first node with a fully developed five-leaflet leaf to stimulate new growth of further flowers (Gibson, 1984; Mattock, 1994). The deadhead method was also mentioned as a method for encouraging stronger growth on roses (Hessayon, 1981).

Heat stress effects on plants

Heat stress is an issue of increasing importance throughout the world as a result of global warming. The vegetative and reproductive development of plants is reduced under heat stress as they use resources to contend with stress (Wahid et al., 2007).

Common responses in various cultivated plant species are reduced germination, plant emergence, and radicle and plumule growth of germinated seedlings as well as abnormal seedlings and poor seedling vigor (Kumar et al., 2011; Piramila et al., 2012; Toh et al., 2008). The damage of high temperature to the reproductive growth of crops first occurs in the external organs. The degree of injury can vary with the difference of heat resistance and sensitivity among different varieties within the same species (Post and Lacey, 1951). The high temperature of 33/30 ˚C day/night caused significantly more abortion of developing pods of cowpea (*Vigna unguiculata* L. Walp.) when comparing plants growing at 33/20 ˚C and some cultivars were more heat tolerant than others (Ahmed et al., 1993).

Heat stress also effects plants physiologically. The increase of membrane permeability and lipid peroxidation induced by high temperature is one of the mechanisms of high temperature injury in plants. Heat induced changes include altered membrane fluidity, ion channel (Ca^{2+}) activation, changes in enzymatic reactions, changes in ROS and redox levels, and translation or degradation of heat stress related proteins (Mittler et al., 2012). Researchers also found that salt and heat stress combination on *Arabidopsis thaliana* resulted in a higher ratio of Na^{+}/ K^{+} in leaves and caused the enhanced expression of the unique transcription factor for ABA (Suzuki et al., 2016). High temperature stress (40 ˚C) reduced the carbohydrate export rate of expanded leaves on the flowering shoots of garden roses by 80% (Jiao and Grodzinski, 1998). The accumulation of antioxidant enzymes and other heat stress related compounds have been found in other ornamental plants such as *Lilium longiflorum* L.

flowers (Yun-Ying et al., 2008), *Gerbera jamesonii* (Chen et al., 2016), *Rhododendron × hybridum* (Shen et al., 2017), *Chrysanthemum morifolium* (Yang et al., 2011), and *Paeonia lactiflora Pall.* (Wu et al., 2016). Morphological parameters and physiological measurements could be used for evaluating the condition of plant growth under heat stress systematically.

Heat stress effects on ornamental plants

Heat stress in many subtropical and tropical regions is a serious issue because of the long duration of temperatures that exceed the heat thresholds for many ornamental plants. High and low temperature ranging from 10 to 42 ˚C caused differences in pollen germination and morphological changes in pollen tube length among different cultivars of ornamental pepper (*Capsicum annuum* L.) (Gajanayake et al., 2011). A temperature increased from 17 to 25˚C shortened the time to axillary bud break and reduced the number of leaves before flowering on two cut flower cultivars of *Rosa* (Marcelis-van Acker, 1995). Increasing leaf necrosis was also considered an indicator of heat damage for *Paeonia lactiflora Pall.* (Wu et al., 2016).

Flower production of ornamental plants has been found to be negatively influenced by heat stress. The flower diameter and the number of flower buds per plant was decreased at 32˚C vs. 20 ˚C for four herbaceous ornamental plants, *Calendula officinalis* L, *Impatients walleriana* Hook. F., *Mimulus× hybridus* Hort. ex Siebert & Voss, and *Torenia fournieri* Linden ex E. Fourn (Warner and Erwin, 2005). Also, one day of 45 ˚C heat treatment caused the wilted plant percentage to increase in comparison to control

gerbera (*Gerbera jamesonii*) seedlings (Chen et al., 2016). In a study of yield of pyrethrum (Suraweera et al., 2020), high temperature at 35 to 40 ˚C for 12 h during each of a 3-day period given during different stages of floral development caused a reduction of flower dry weight per plant and a reduction of petal pyrethrin concentration compared with control plants which was believed to be an indication of an effect on flower senescence. In rice (*Oryza sativa* L.), sterility was observed with as little as 1 h of heat stress over 33.7 ˚C in an effort to discern heat tolerant vs. heat sensitive rice cultivars (Jagadish et al., 2007). In herbaceous peony, the days to flowering was reduced as the growing temperature rose from 22/10 to 28/22 ˚C day/night, but the percentage of flowering shoots with bud abortion increased significantly and the average number of flowers per plant was reduced (Kamenetsky et al., 2003). Flower diameter and flower dry weight decreased due to higher temperature exposure of *Campanula* plantsto at 14, 17, 20, 23, or 26 ˚C fixed temperatures during the vegetative growth period and up until flowering (Niu et al., 2001).

Heat stress research progress on roses

High temperatures have been found to affect rose flower morphology. Earlier studies were with greenhouse grown cut flower rose cultivars and many of these studies measured the effect on a flowering stem so that the response of just the flower to temperature was not measured. For example, an increase in the average growing temperature resulted in a reduction of flowering stem fresh weight (van den Berg, 1984). However, Post (1949) found that a growing temperature of 32.2 ˚C caused flower buds

in a cut flower crop to open when very small. Moe and Kristoffersen (1969) found that increasing temperature resulted in a decrease in petal number, length, and width for flowers of ‘Baccara’ cut roses. Byrne et al. (1978) found that increasing temperatures decreased petal number on ‘Cara Mia’ cut rose flowers, but there was no effect of photoperiod. Shin et al. (2001) found that flower fresh and dry weight decreased as growing temperature increased for greenhouse grown ‘Kardinal’ cut roses. In growth chamber studies, Grossi et al. (2004) and Kyalo et al. (1996) found that flower size on several cultivars commonly grown as potted rose plants was smaller when exposed to summer-like conditions in comparison to plants exposed to winter-like conditions.

Breeding for improved heat tolerance in garden roses is a long-term effort, but progress has been made for phenotypical screening of rose genotypes. An important aspect of heat tolerance in garden roses is to determine how high temperature affects the flowers. In a field study, Greyvenstein et al. (2015) found that dry weights of fully opened rose flowers was reduced by 4.3 to 6.5 % per 1 ˚C increase in temperature depending on the garden rose cultivar studied when comparing flowers opening during the warmest part of the summer season to those opening during the cooler spring and fall seasons. They also found that the temperature during the 8 to 14 days prior to opening were the most influential on the final weight. Also in a field study, Liang et al. (2017a) found that flower dry weight, and petal number and diameter was lower when measured during the summer vs. spring measurements on several diploid populations of garden roses. In a growth chamber study, Greyvenstein et al. (2014) found that flower dry weight measured when flowers became fully open was reduced by high temperature

treatment and that the most heat sensitive period during floral development was when flower buds were recently visible without manipulating the foliage (about 1-2 mm diameter) which occurs well before the flower opens. A high temperature effect on a specific size flower bud was not determined. Using a high temperature chamber, the same authors assessed heat tolerance among rose cultivars by exposing whole plants with flower buds 1-2 mm in diameter to a 3 h heat treatment at 44 ˚C (Greyvenstein Ockert et al., 2015). Flower bud abortion was assessed ten days after the heat treatment and ranged from 34 to 55 %, depending on cultivar, on heat treated plants when compared to untreated controls. Dry weight was measured on surviving flowers when they reached the fully open stage and the heat treatment was found to reduce flower weight by an average of 19 % with no statistical difference being found between cultivars which was likely due to the high rate of floral abortion in this study (Greyvenstein Ockert et al., 2015). A further study showed that the rate of floral abscission and leaf damage on pot grown plants with 1-2 mm diameter buds after the same heat chamber treatment was negatively correlated with summer flowering intensity of field grown plants of the same 18 cultivars (Greyvenstein O. et al., 2019). Dry weight was not measured in this study and floral diameter and petal number were not measured in any of the studies just discussed. In another study, a 1 h heat treatment at 44 ˚C of potted plants with 1-2 mm diameter buds did not result in flower bud abortion so that a reduction in flower diameter, petal number, and flower dry weight in comparison to control plants could be seen and measured for progeny in 10 different garden rose breeding populations (Liang et al., 2017b). However, in the genetic analysis flower

diameter was the only measurement to show a genotype by environment interaction and the variance was considered so small in comparison to the genetic effect that the use of the 1 hour treatment at 44 ˚C for screening progeny was considered limited (Liang et al., 2017b). These authors recommended studying the use of a longer heat treatment, though not long enough to cause flower bud abortion, or a milder temperature for a longer period to optimize the heat treatment to better differentiate the level of floral high temperature tolerance among rose genotypes.

CHAPTER II

THE EFFECTS OF SPENT FLOWER REMOVAL ON REBLOOMING AND BRANCHING ARCHITECTURE

Synopsis

Four plant types of garden roses classified as Shrubs were chosen to study the effects of spent flower removal on the reblooming and branching architecture of garden roses. These were Mounding: ‘Meiggili’, Upright: ‘RIPhud’ (bushy with single flowers) and ‘Belinda’s Dream’ (double flowers on growth similar to a Hybrid Tea), and Rounded: ‘Bucbi’ (cluster flowered similar to a Floribunda). Spent flower removal is commonly practiced on remontant garden roses as a landscape management tool to hasten rebloom. The architecture of rose bushes is characterized by variables including the number and length of the various orders of shoots such as primary, secondary, etc. In February 2019, dormant plants were field planted and, in June 2019, the growing shoots were all pruned by about 20 % to synchronize the growth. Spent flower removal pruning then started on treated plants while half of the plants in each cultivar were unpruned controls. Spent flower removal had no effect on the days to rebloom between flushes of flowering. ‘Belinda’s Dream’ had the longest reblooming period compared with other cultivars. The current season growth and primary shoot number were not affected by spent flower removal. The location and cultivar effects were significant for several variables regardless of pruning treatments which was possibly due to different climates at the two locations and different growth habits among the cultivars. Plants in Somerville

exhibited a higher number of secondary and tertiary shoots than those in Overton regardless of cultivar. In addition, most cultivars produced more total current season growth and half of the cultivars had more quaternary shoots when grown in Somerville. This is likely attributable to the longer growing season in Somerville as characterized by a longer period of higher average temperatures (about 2 ˚C) and 2 months longer without freezing temperatures than at Overton. Also, less nutrition and energy may have been available for secondary and tertiary growth because more primary shoots were produced in Overton than in Sommerville before the spent flower removal treatments.

Objective of this project:

To determine the effects of spent flower removal (deadhead pruning) on reblooming time and architectural branching characteristics of four garden rose cultivars with different growth habits. A complete set of treated plants was grown at each of two locations to determine if this factor has an effect on growth responses.

Material and methods

Plant material and equipment

Four rose cultivars classified as Shrub types were used for the pruning study. ‘Meiggili’ (Peach Drift®) has a mounding habit with flowers in clusters, ‘RIPhud’ (Miracle on the Hudson®) has a bushy habit with single flowers, ‘Belinda’s Dream’ has an upright habit with double flowers similar to a Hybrid Tea and ‘Bucbi’ (Carefree Beauty^{TM}) has a rounded habit similar to a Floribunda.

In February 2019, dormant bare root plants were planted in 4 blocks with 4 plants of each cultivar per block using a randomized complete block design at the East Farm of the Texas A&M AgriLife Research and Extension Center in Overton, TX (32.2746˚ N latitude, 94.9786˚ W longitude) with a duplicate planting made at the Texas A&M University HORTTREC field in Somerville, TX (30.5278˚ N latitude, 96.4231˚ W longitude). The average temperature and precipitation of the two locations are in Table 1 and Table 2.

Before planting, plants of each cultivar were pruned at 20 cm above the crown or graft union with 5 primary shoots left remaining on Peach Drift plants and 3 primary shoots left on plants of the other cultivars. At each location, 91 cm wide beds spaced 3.7 m apart from center to center were covered with polyethylene ground cloth (© DeWitt, Sikeston, MO). In each bed, the roses were planted in a single row down the bed spaced 1.2 m apart. Plants were drip irrigated as needed at both locations, and plants in Overton were fertilized with 7.32 g N per m^2 bed space using Nature's Source Professional 10-4-3 (Nature's Source, Sherman, TX) added weekly. Fungicides and miticides were used as needed for pest control at both field locations.

Table 1 Monthly average temperatures and precipitation at Overton, TX for 2019, reprinted from National Weather Services, January, 2020 (NOAA, 2020).

Month	Average (˚C)	Average min (˚C)	Average max (˚C)	Min(˚C)[z]	Max(˚C)	Total precipitation (mm)
January	7.3	2.2	12.9	-5	21	84.8
February	10.0	5.4	14.7	-4	25	55.1
March	12.0	6.1	17.9	-6	26	62.0
April	17.3	11.6	23.4	-2	30	251.0
May	22.6	17.9	28.0	12	32	250.7
June	24.9	19.6	30.5	14	34	180.8
July	27.1	22.1	32.8	16	35	18.5
August	28.6	23.7	34.6	22	38	27.2
September	27.2	21.5	34.1	19	38	91.4
October	17.9	12.3	24.7	0	34	102.9
November	11.7	5.6	18.7	-8	27	13.5
December	9.9	3.9	17.1	-3	27	28.7

[z]Freeze day end to start: April 2nd to Oct 31th.

Table 2 Monthly average temperatures and precipitation at Sommerville, TX for 2019, reprinted from National Weather Services, January, 2020 (NOAA, 2020).

Month	Average (˚C)	Average min(˚C)	Average max (˚C)	Min (˚C) [z]	Max (˚C)	Total precipitation (mm)
January	10.1	5.3	15.2	-2	23	122.2
February	12.8	9.7	16.9	0	27	53.9
March	15.2	10.6	20.4	-3	28	31.7
April	19.7	14.4	25.7	3	32	141.0
May	24.3	20.5	29.4	14	34	148.1
June	26.9	22.8	32.2	17	35	102.4
July	28.7	24.3	34.5	20	38	1.0
August	29.9	25.7	36.5	24	38	42.7
September	28.4	24.8	34.4	22	38	56.1
October	21.3	16.1	27.7	2	36	77.7
November	14.7	8.7	21.1	-2	29	32.3
December	12.8	6.8	19.8	-2	28	14.2

[z]Freeze day end to start: March 5th to November 13th.

Pruning methods

In early June 2019, approximately 2 to 3 nodes below the flower were removed from each primary shoot on all plants to synchronize growth for the pruning experiment (Figure 1). Each shoot was left with a distal node consisting of a bud with a fully developed 5-leaflet leaf. Half of the plants in each cultivar (2 plants per block) were randomly chosen to be pruned with the other half left as non-pruned controls. The pruning treatment was started in June 2019 as growth resumed and plants began to re-flower after pruning for synchronization. As the majority of the shoots on a plant reached the fully open stage and petals began to fade and fall, the date was recorded, and the flowers were removed from the pruned plants at a node with a mature 5-leaflet leaf that was 2 or 3 nodes subtending the flower or flower cluster (Figure 2). On non-pruned plants, flowering flush dates were recorded when the majority of the flowers in the current flowering flush faded and petals began to fall. Pruning was terminated at the end of the growth cycle in early September. After this point, flowers were removed at the peduncle when fully open on pruned plants to maintain the treatment effect of deadheading while preventing the encouragement of vigorous growth that would interfere with the development of normal autumn dormancy which is a response that is generally observed to be a result of standard pruning for deadheading in the fall in this climate. During this period, all plants were allowed to grow and develop dormancy.

In November 2019, plants were dormant so that measurements of plant architecture could be made. First, the total number of primary shoots were counted on each plant. Primary shoots were those that began growth from the original canes that were present when the plants were planted. Three major primary shoots with secondary growth present were then chosen randomly on each plant. The total length of all the growth on each of these 3 primary shoots was measured. Then the number of secondary, tertiary, and quaternary shoots originating from these primary shoots as shown in Figure 1 was counted. A very few quinary shoots were observed, but the number was too small to be considered worth counting.

Prior to analysis, the number of each type of shoot was determined per primary shoot for each plant. Then the data for the two similarly treated plants of each cultivar in each block was averaged and these averages were used in the final analyses. Three factors including location, pruning treatment and cultivar were analyzed by ANOVA for each variable measured. This experiment followed a randomized complete block design.

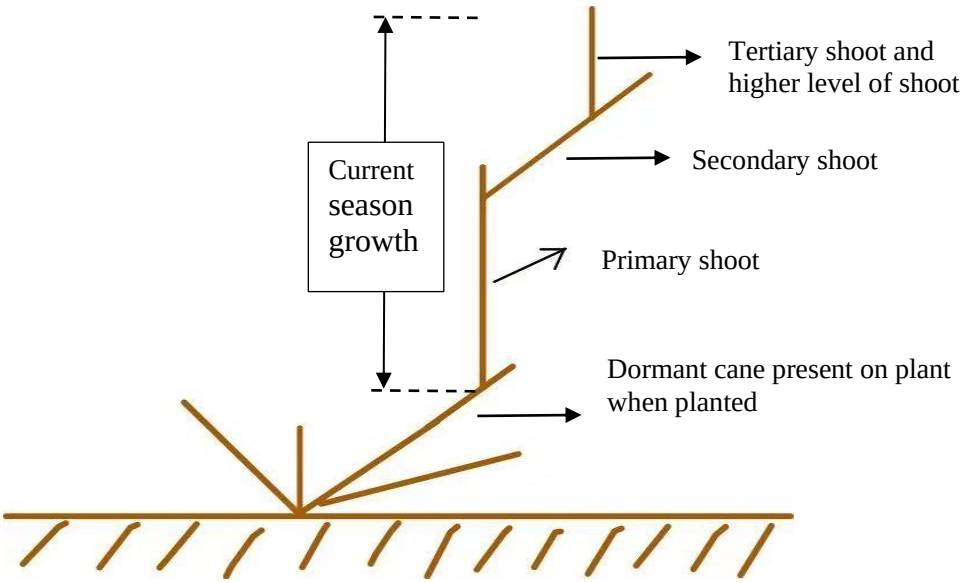

Figure 1 Simplified plant architecture shoot hierarchy on garden roses.

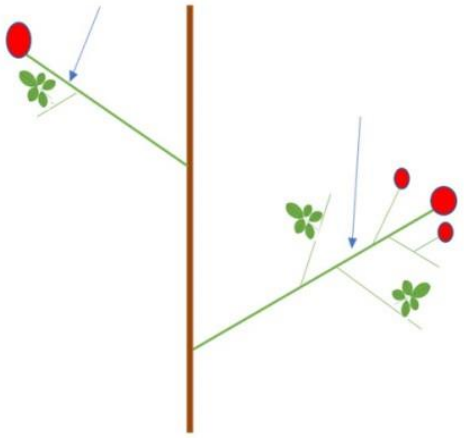

Figure 2 Cutting points for the spent flower removal method. Note the presence of the five-leaflet leaves.

Results

The three-way ANOVA including the factors of cultivar, location, and pruning treatment showed significant main and interaction effects depending on the analysis variable (Table 3).

Table 3 Three-way ANOVA (F-value) of the effects of pruning, cultivar and location on garden roses in 2019.

Measurements	Days to rebloom	Current season growth (cm)	Primary shoot number	Secondary shoot number	Tertiary shoot number	Quaternary shoot number
Cultivar	47.1*[z]	110.9*	64.0*	20.1*	32.8*	21.3*
Location	5.3*	73.1*	35.2*	35.1*	32.2*	30.4*
Pruning	1.9 NS	0.0 NS	0.1 NS	5.7*	0.2 NS	1.6 NS
P× C[y]	2.0 NS	1.0 NS	0.3 NS	2.4 NS	0.4 NS	0.2 NS
L× C	1.9 NS	8.9*	6.0*	1.8 NS	1.0 NS	4.8*
P× L	5.8*	0.7 NS	0.1 NS	0.2 NS	0.6 NS	0.4 NS
P ×C× L	0.3 NS	2.2 NS	0.4 NS	1.2 NS	0.6 NS	0.2 NS

[z]NS = No significance; *= Significance at the 5% level.
[y]P: pruning; C: cultivar; L: location

Days to rebloom

Spent flower removal had no effect on days to rebloom, but there was an interaction of pruning and location (Table 3). Further analysis showed days to rebloom was not affected by spent flower removal in either location (Table 4). This variable appeared to be more strongly affected by the main effect of location as rebloom occurred in 11.0 days in Overton regardless of pruning treatment or cultivar which was significantly less than the 12.3 days observed in Somerville (Table 4). But overall, the differences due to location or

pruning were small and of no practical consequence. There was a main effect of cultivar on days to rebloom (Table 3). ‘Belinda’s Dream’ had the longest cycle of more than two weeks with other cultivars taking fewer days to rebloom (Table 5).

Table 4 The effect of the pruning and location interaction and the main effect of location on mean days to rebloom at Sommerville and Overton, TX.

	Location	
Treatment	Overton	Somerville
Pruned	11.3 a[z]	11.2 a
Non-pruned	10.8 a	13.2 a
	Location averaged over treatments	
	Overton	Somerville
	11.0 a	12.3 b

[z]Student t-test at α=0.05. Similar letters indicate differences are not significant within location.

Table 5 The main effect of cultivar on mean days to rebloom on 4 garden rose cultivars.

Cultivar	Mean (day)
Belinda's Dream	17.1 c[z]
Bucbi	11.1 b
RIPhud	9.3 ab
Meiggili	9.0 a

[z]Tukey’s HSD test at α=0.05. Similar letters indicate differences are not significant.

Current season growth

There was an interaction of location and cultivar for current season growth though both factors were also significant as a main effect (Table 3). For ‘Belinda’s Dream’, ‘RIPhud’, and ‘Meiggili’, the current season growth in Somerville was more than in Overton regardless of pruning treatment (Table 6). Growth in Somerville was also more than in Overton for ‘Bucbi’, but this difference was not significant.

Table 6 The effects of location by cultivar on mean current season growth, primary shoot number and quaternary shoot number.

Cultivar	Current season growth (cm)		Primary shoot number		Quaternary shoot number	
	CS[z]	OV	CS	OV	CS	OV
Belinda's Dream	77.6 b[y]	57.4 a	12.2 a	15.0 a	0.0 b	0.0 a
Bucbi	80.1 a	73.9 a	8.7 a	12.1 a	5.5 a	2.3 a
RIPhud	76.3 b	50.8 a	9.3 a	10.3 b	5.3 a	1.7 a
Meiggili	38.7 b	33.2 a	17.1 a	25.6 a	3.2 b	1.7 a

[z]CS: Somerville; OV: Overton.
[y]Student t-test at α=0.05. Similar letters indicate differences are not significant between locations within cultivar.

Primary shoot number

Pruning had no effect on the number of primary shoots regardless of cultivar or location due to the fact that these shoots grew prior to the start of pruning treatments (Table 3). However, there was an interaction of location and cultivar. Plants at Overton had more primary shoots than those in Somerville for all cultivars except 'RIPhud' for which there was no significant difference between locations (Table 6).

Secondary shoot number

Spent flower removal (pruning treatment) served as a significant main effect factor as untreated plants had more secondary shoots compared to pruned plants (Table 3, Table 7). There was also a main effect of location regardless of pruning treatment and cultivar on number of secondary shoots (Table 3). There were more secondary shoots on plants at Somerville when compared to plants at Overton (Table 7). Secondary shoot number was also different among cultivars (Table 3). 'RIPhud', 'Meiggili' and 'Bucbi' had more

secondary shoots than ‘Belinda’s Dream’ (Table 7).

Table 7 The effect of cultivar, pruning and location on mean secondary shoot number on garden roses grown in Somerville and Overton, TX during 2019.

Cultivar		Treatment		Location	
Belinda's Dream	3.5 b[z]	Pruned	4.6 b[y]	Somerville	5.5 a[y]
Bucbi	5.0 a	Non-pruned	5.1 a	Overton	4.2 b
RIPhud	5.1 a				
Meiggili	5.7 a				

[z]Tukey’s HSD test at α=0.05. Similar letters indicate differences are not significant.
[y]Student t-test at α=0.05. Similar letters indicate differences are not significant.

Tertiary shoot number

There were significant single factor main effects of location and cultivar on tertiary shoot number (Table 3). ‘Belinda’s Dream’ had significantly fewer tertiary shoots than the other cultivars regardless of pruning treatment or location (Table 8). Plants in Somerville had more tertiary shoots than those at Overton regardless of spent flower removal or cultivar (Table 8).

Table 8 The effect of cultivar and location on mean tertiary shoot number on garden roses grown in Somerville and Overton, TX during 2019.

Cultivar		Location	
RIPhud	7.9 a[z]	Somerville	7.3 a[y]
Bucbi	7.4 a	Overton	4.4 b
Meiggili	6.9 a		
Belinda's Dream	1.4 b		

[z]Tukey’s HSD test at α=0.05. Similar letters indicate differences are not significant.
[y]Student t-test at α=0.05. Similar letters indicate differences are not significant.

Quaternary shoot number and quinary shoot number

Pruning treatment had no effect on quaternary shoot number (Table 3). However, there was a significant interaction between location and cultivar. Plants in Somerville had more quaternary shoot numbers than in Overton for ‘RIPhud’ and ‘Bucbi’, whereas there was no difference for ‘Meiggili’ (Table 6). ‘Belinda’s Dream’ plants exhibited almost no quaternary shoots in Somerville and none in Overton.

‘Belinda’s Dream’ plants had no quinary shoots. Plants of ‘Meiggili’, ‘RIPhud’ and ‘Bucbi’ were only observed to have a very few quinary shoots with numbers that were not sufficient to warrant counting and analysis in this experiment.

Discussion and conclusion

The days to rebloom varied among cultivars with ‘Belinda’s Dream’, which has a growth habit similar to Hybrid Tea roses, and ‘Bucbi’, which has a growth habit similar to Floribunda roses, taking the longest to rebloom. Hybrid Tea and Floribunda roses have generally been observed to take a longer time to rebloom than modern Shrub type roses. But differences between cultivars in the time it takes to reflower has not been documented in the literature for garden roses and needs to be studied for a much broader array of cultivar classifications and types of remontant roses.

However, all remontant roses are generally expected to exhibit faster reblooming in response to spent flower removal or ‘deadheading’. Surprisingly, none of the cultivars in this study exhibited faster reblooming in response to spent flower removal. The deadhead pruning procedure used in the present study has been a generally accepted way

to hasten rebloom of garden roses for many decades (Gibson, 1984; Hessayon, 1981; Scanniello and Bayard, 1990; Mattock et al., 1994), especially for hybrid teas and floribundas (Hessayon, 1981). However, this response has not been experimentally quantified and needs to be studied in a wide array of garden rose cultivars of different classifications with different growth habits as well. There have been many studies of the effects of pruning in cut rose production, but the type of pruning used is inherently different than the technique used in the present study. In cut rose production, the shoot is typically removed at the first or second five-leaflet leaf from the proximal end of the shoot (Dole and Wilkins, 2005; Kool et al., 1997). But pruning as described here removes the spent flower at the first five-leaflet leaf from the distal end of the shoot which has been shown to increase the number of breaks on cut rose cultivars when compared to pruning at the proximal end (Zieslin and Mor, 1981). Most pruning studies on rose cut flower plants have been to study effects of pruning on winter cut flower production (Hassanein, 2010; Kool et al., 1997; Zieslin et al., 1975; Zieslin et al., 1976) in contrast to the summer growing season in the present study.

Days to rebloom was not affected by pruning on plants at Overton or Somerville (Table 4) even though there was a two-way interaction between pruning and location (Table 3). However, there was a main effect of location which appeared to be the dominant factor (Tables 3 and 4). Regardless, the difference in days to rebloom between the two locations (1.3 days) was too small to be of any practical value.

Plant architecture of garden roses is considered an important part of their ornamental value (Crespel et al., 2014) and traits such as seasonal growth and the

number of primary, secondary, and tertiary shoots have been deemed important characters describing this aspect (Crespel et al., 2013; Wu et al., 2019; Young et al., 2019). The number of primary shoots was not affected by pruning because their number was established prior to the synchronization pruning done at the beginning of the treatment period. The greater number of primary shoots on most cultivars in Overton could be explained by the cooler average temperatures at that location during the early spring period which could have allowed for better root establishment prior to the first flush of bud break and growth. The effects of temperature on the establishment and early growth characteristics of freshly planted dormant rose plants in late winter has not been studied.

The number of secondary shoots was unexpectedly reduced by pruning. Removing the spent flower at the first five-leaflet leaf does remove a number of smaller buds between the cut and the flower that could account for the difference, but the actual difference is small and may not be of practical importance. Quicker rebloom has been traditionally emphasized as the primary reason for spent flower removal over other reasons such as the number of returning flowers. This effect of pruning needs to be studied further using a broader array of cultivar growth types and classifications.

Plants in Somerville exhibited more secondary and tertiary shoots than those in Overton regardless of cultivar. Since there were more primary shoots on the plants in Overton, the energy available for the production of secondary shoots could have been spread over these additional shoots so that the number of secondary shoots per primary shoot could be lower. Also, the higher average temperatures and the longer growing

season in Somerville as characterized by a longer period of higher average temperatures and 2 months longer without freezing temperatures than at Overton (Tables 1 and 2) likely influenced this growth. Marcelis van-Acker (1995) studied the effect of temperature on resulting shoot growth characteristics after flower removal for two cut flower cultivars, but the effect of temperature on the number of buds breaking from buds left intact after flower removal on rose shoots on actively growing plants has not been studied. In addition, most cultivars produced more total current season growth and half of the cultivars had more quaternary shoots when grown in Somerville which could also be explained by the longer growing season without freezing temperatures than at Overton (Tables 1 and 2). A higher number of structural shoots of each order has been shown to be important to the ornamental value of a rose cultivar (Wu et al., 2019; Young et al., 2019). The fact that only some of the cultivars showed the tendency to produce more structural higher order shoots in the warmer environment of the Somerville location as vs. the cooler environment of the Overton location indicates that these measurements could be of value when selecting cultivars for heat tolerance in a breeding program. Another notable effect of cultivar is that ‘Belinda’s Dream’ had fewer secondary and tertiary shoots than the other cultivars and was the only cultivar to not have quaternary shoots. Zieslin et al. (1976) found differences in the rate of correlative inhibition as measured by the number of shoots produced per plant during the first growing season after winter planting of several cut flower cultivars and this is evidently also seen in garden rose cultivars. The effect of growing temperature on bud break numbers and the ability of the resulting new shoots to overcome apical dominance of

spent flowers quickly has not been studied on garden roses growing in a humid subtropical environment.

CHAPTER III

CHARACTERIZATION OF FLORAL HEAT TOLERANCE OF GARDEN ROSES

Synopsis

Heat stress in many subtropical and tropical regions is a serious issue because of the long duration of temperatures that exceed the heat thresholds for many plants. Heat and drought stress tolerance are essential for plants that are useful in landscapes. Garden roses commonly suffer from high summer temperature in southern states like Texas, USA so that selection of cultivars with heat tolerance is important to producers and consumers alike. An important aspect of heat tolerance of ornamental plants is the response of the flowers to high temperature.

In this project, commercial garden rose cultivars were exposed to brief high temperature treatments and compared to untreated controls to determine the effects of heat on floral parameters including petal number, flower diameter and flower dry weight. In the heat chamber, plants of 9 cultivars with 4 mm diameter buds were exposed to temperatures of 36 ˚C, 40 ˚C, or 44 ˚C for durations of 1 h, 3 h, or 5 h in factorial combination. Two cultivars were exposed to the same treatments with flowers at both 2 and 4 mm in diameter.

By comparison of treated and control groups of each cultivar, a range of floral parameter responses to the heat treatments was measured. Dry weight was the most sensitive parameter measured. The number of treatments different from the control determined using Dunnett's test and the parameters affected by the temperature x duration

factors as determined by ANOVA were used to categorize the cultivars studied. The Heat Sensitive cultivars ‘CHEWNICEBELL’ and ‘ZLEMarianne Yoshida’ and the Moderately Heat Sensitive cultivar ‘Winnipeg Parks’ showed the largest number of treatments reduced in comparison to the control for dry weight and significant treatment effects for other measured parameters. In contrast, the Moderately Heat Tolerant cultivars ‘Champlain’, ‘Meipeporia’, ‘Morden Blush’, and ‘RADrazz’ exhibited a fewer number of treatments reduced in comparison to the control for dry weight and fewer significant treatment effects for other measured parameters in comparison to the heat sensitive groups. And the Heat Tolerant cultivars ‘RADtko’ and ‘RIPhud’ exhibited no effect of the heat treatments on the floral parameters measured. Rose genotypes differed in their heat tolerance as measured by flower size, petal number, and dry weight. Exposure of plants with buds 4 mm in diameter to 44˚C for 3 or 5h was the most effective treatment for determining floral heat tolerance for the genotypes studied.

Objectives

The purpose of this project focused on the effect of a range of high temperatures for various lengths of time given as a brief heat shock treatment on floral parameters of garden roses as a way of characterizing floral heat tolerance in garden roses.

Material and methods

Material

The *Rosa* L. cultivars 'Champlain', 'RIPhud' (Miracle on the Hudson®), 'Morden Blush', 'RADrazz' (Knock Out®), 'RADtko' (Double Knock Out®), and 'Winnipeg Parks' were received as own-root bare root plants from Bailey's Nursery, Newport, MN. 'CHEwnicebell' (Oso Easy® Italian Ice®), 'Meipeporia' (Oso Easy® Double Red®), and 'ZLEMarianne Yoshida' (Oso Easy® Petit Pink) were received as rooted liners in 5-cm pots from Spring Meadow Nursery, Grand Haven, MI. The rose plants were potted in 1 L pots using a peat: perlite mix (BM-6) (Berger's Headquarters, Saint-Modeste, QC, Canada) which were placed in a polycarbonate covered greenhouse in October 2019 at the Texas A&M AgriLife Research and Extension Center in Overton, TX. The plants were fertilized with 200 $mg \cdot L^{-1}$ N from a 15N – 5.4P – 15K fertilizer with water (Everris NA Inc, Dublin OH), irrigated as needed, and pesticides and fungicides were used twice a week for disease and pest control. Based on the evaluation of roses in the field (Byrne D. et al., 2010; Harp et al., 2019; Mackay et al., 2008; Zlesak et al., 2017), unpublished data on field evaluation of garden roses during the summer growing season (including flower intensity and landscape and disease ratings), and suggestions by breeders and nurseries the cultivars received were categorized as heat tolerant or susceptible (Table 9).

Fluorescent lights (30 $mmol \cdot m^{-2} \cdot s^{-1}$) were set up above the plants in the greenhouse to extend the photoperiod to 14 h (6 am to 8 pm). Day and night temperature of 24/17 ˚C was maintained in the greenhouse. When the plants were well established, the shoots were pinched to synchronize growth as needed.

Table 9 Designated heat tolerance of 9 cultivars assigned prior to experiments based on referenced studies.

Heat tolerant	References[z]	Heat sensitive	References[z]
Meipeporia	Overton Center field evaluation	Champlain	College Station field evaluation
RADrazz	Byrne et al, 2010; Harp et al, 2019; Mackay et al, 2008	CHEwnicebell	College Station field evaluation
RADtko	Byrne et al, 2010; Harp et al, 2019; Mangandi et al., 2013	Morden Blush	Overton Center field evaluation; Zlesak et al, 2017
RIPhud	Overton Center field evaluation	Winnipeg Park	Overton Center field evaluation
ZLEMarianne Yoshida	Overton Center field evaluation		

[z] Overton or College Station field evaluations were based on flower intensity and landscape ratings for the whole canopy which included the factors of climate, pests and diseases during the full growing season. References cited can be found in the References list.

Figure 3 The establishment of rose plants in 1L pots at Overton, TX.

Methods

Plants were grown to a stage such that each plant had several shoots with buds at 4 mm in diameter during April and May 2020. Two buds on each of 3 plants were marked with loose fitting paper hang tags and there were 9 treatments × 3 replications × 9 cultivars and one control group. The plants were arranged in a randomized complete block design in the heat chamber with a humidifier under constant light as previously described (Greyvenstein et al., 2014). The heat chamber (approximately 4 m^2) was equipped with a florescent light (25 $mmol \cdot m^{-2} \cdot s^{-1}$) above the bench with a radiant heating element installed under this bench and a humidifier at the corner for maintaining the relative humidity of 75 % (OMEGA Engineering Inc, Norwalk, CT). A circulation fan was used to maintain uniform conditions in the chamber. The desired temperature was maintained ± 1˚C with a controller (APE4100 Eclipse F60 Digital Environmental Controller, Autopilot®, San Francisco, CA). The control plants were left in the greenhouse while treated plants were exposed to the temperature x duration treatment combinations. The temperatures used were 36 ˚C, 40 ˚C and 44 ˚C in factorial combination with the durations of 1 h, 3 h, 5 h. Three single plant replications with 2 flowers on each plant were used for each treatment. Plants were moved back to the greenhouse after treatment. Since the temperature treatments could not be applied all at the same time, each of the three temperature treatments were applied on consecutive days for logistical purposes.

Two cultivars [‘CHEWnicebell (Oso Easy® Italian Ice®) and ‘RADtko’ (Double Knock Out®)] were used to test the effects of heat on two bud sizes during August to

November 2020. Buds that were either 2 mm or 4 mm diameter were labeled on the same plant prior to heat treatments that were then performed as described above.

When each labeled flower reached the fully open stage after return to the greenhouse, measurements were recorded for flower diameter, petal number and flower dry weight (Liang. et al., 2017). The flower diameter was measured at the widest point of the flower and the petals were counted. The dry weight of each flower (including the peduncle) was measured after drying for 48 h at 60 ± 5˚C.

Figure 4 Heat chamber with heater under the bench of plants and light and humidity sensors.

Statistical analysis

The statistical analysis was done using JMP software, Version 14.2.0 SAS Institute Inc. Since the untreated control (considered 0 h duration time) was not part of the temperature x duration factorial treatment combination, the analysis was done in two stages. Initially, the multicomparison of each treatment compared individually to the control group was done using Dunnett's test. An ANOVA was then performed using the factorial treatment structure of the temperature x duration treatment factors to evaluate the effects of heat stress. Tukey's Honest Significant Difference test and Student's t-test was used for analyzing the treatment differences within the factorial set of treatments.

Results

Comparison of control and heat-treated flowers

A normality test indicated that the data were normally distributed except for flower diameter for 'Morden Blush' (Table 10). Thus, the data was considered normally distributed for further analyses.

None of the flower buds, flower peduncles, or leaves on the heat-treated plants of any cultivar exhibited any visible damage after the return to greenhouse conditions at the end of the high temperature treatment. All labeled flowers developed to the fully open stage so that they could be harvested for data collection. Initially an ANOVA including the factors cultivar, temperature and duration was conducted for comparing responses to temperature × duration among all cultivars. The results exhibited a three-way interaction indicating that the response to temperature × duration was dependent on cultivar for the

floral parameters measured (flower dry weight, flower diameter, and petal number). The results were therefore analyzed and reported by cultivar. In addition, all floral parameter means for the 36 ˚C, 1 hour treatment for all cultivars was either equal to or less than the control so that the mean for this treatment could function as a control in the ANOVA factorial analysis for the temperature × duration set of treatments.

Table 10 Shapiro-Wilk test for data normality with probability < W.

	Shapiro-Wilk W test		
Cultivar	Dry weight (g)	Flower diameter (cm)	Petal number
Champlain	NS[z]	NS	NS
RADtko	NS	NS	NS
Meipeporia	NS	NS	NS
CHEwnicebell	NS	NS	NS
RADrazz	NS	NS	NS
RIPhud	NS	NS	NS
Morden Blush	NS	*	NS
ZLEMarianne Yoshida	NS	NS	NS
Winnipeg Park	NS	NS	NS

[z]NS: nonsignificant, normally distributed; *: significant means the distribution is not normal; α= 0.05.

Results by cultivar

'Champlain'

Flower dry weight was reduced in comparison to the control by treatment at 44 ˚C for 3 or 5 hours, but there was no effect on flower diameter or petal number in reference to the control regardless of treatment (Table 11). For the factorial combination of temperature and duration treatments, there was an interaction of temperature × duration for dry weight, though 44 ˚C resulted in lower dry weight in comparison to 36 ˚C regardless of duration (Table 12 and Figure 5). For flower diameter, there was a main effect (significant different means) of temperature with 44 ˚C resulting in the smallest flowers (Tables 12 and 13). Petal number of this cultivar was unaffected by the temperature treatments (Tables 12 and 13).

Table 11 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters of the rose 'Champlain'.

Temperature(˚C)	Duration (h)	Dry weight (g)	Flower diameter (cm)	Petal number
Control	N	0.49	5.0	27.3
36	1	0.53 NS[z]	5.1 NS	26.5 NS
	3	0.49 NS	5.0 NS	29.3 NS
	5	0.49 NS	5.0 NS	24.3 NS
40	1	0.43 NS	5.1 NS	25.0 NS
	3	0.51 NS	5.3 NS	29.0 NS
	5	0.47 NS	5.1 NS	27.8 NS
44	1	0.40 NS	4.8 NS	25.7 NS
	3	0.34*	4.5 NS	26.5 NS
	5	0.38*	4.9 NS	26.5 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 12 Two-way ANOVA (F-values) of the effects of temperature and duration for three floral parameters of the rose ‘Champlain’.

Source	Dry weight (g)	Flower diameter (cm)	Petal Number
Temperature	27.3*[z]	4.1*	0.2 NS
Duration	0.0 NS	0.1 NS	1.9 NS
Temp.× Duration	3.1*	0.7 NS	0.9 NS

[z]NS = No significance; *= Significance at 5% level.

Table 13 The effect of temperature on three floral parameters (means) on the rose ‘Champlain’.

Temperature (˚C)	Dry weight (g)	Flower diameter (cm)	Petal number
36	0.50 a[z]	5.04 a	26.7 a
40	0.47 ab	5.16 a	27.3 a
44	0.38 b	4.70 b	26.2 a

[z]Tukey’s HSD test at α= 0.05. Similar letters indicate differences are not significant.

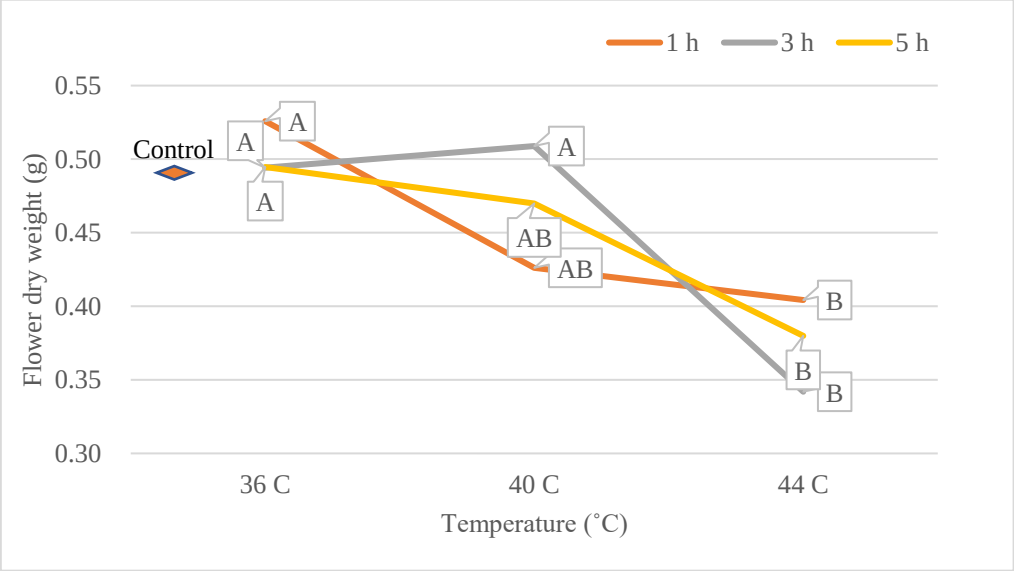

Figure 5 Means of temperature by duration for flower diameter of the rose ‘Champlain’. Different letters refer to significantly different means within each duration (three points of the same line).

‘CHEWnicebell’

The dry weight of ‘CHEWnicebell’ flowers was reduced by all temperature and duration treatment combinations when compared to the control (Table 14). Flower diameter was reduced by 1 and 5 hours at 40 ˚C and by all durations at 44 ˚C and petal number was reduced by 3 and 5 hours at 44 ˚C when compared to the control (Table 14). When considering the temperature × duration factorial treatments, all variables exhibited a main effect of temperature only (Table 15) with all parameters significantly reduced by the highest temperature treatment when compared to the lower two temperatures regardless of duration (Table 16).

Table 14 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett’s test for three floral parameters of the rose ‘CHEWnicebell’.

Temperature (˚C)	Duration (h)	Dry Weight (g)	Flower Diameter (cm)	Petal number
control	N	0.30	4.4	19.8
36	1	0.25*[z]	3.7 NS	19.3 NS
	3	0.24*	3.7 NS	19.0 NS
	5	0.26*	3.6 NS	20.5 NS
40	1	0.24*	3.2*	19.1 NS
	3	0.26*	3.7 NS	20.1 NS
	5	0.25*	3.3*	19.0 NS
44	1	0.24*	2.8*	17.8 NS
	3	0.24*	2.7*	16.6*
	5	0.22*	2.6*	15.0*

[z]NS = No significance; *= Significance at the 5% level.

Table 15 Two-way ANOVA (F-values) of the effects of temperature and duration for three floral parameters of the rose 'CHEWnicebell'.

Source	Dry weight(g)	Flower diameter (cm)	Petal number
Temperature	4.3*[z]	16.3*	5.5*
Duration	0.2 NS	1.0 NS	0.2 NS
Temp.× Duration	0.9 NS	0.7 NS	0.8 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 16 The effect of temperature on three floral parameters (means) on the rose 'CHEWnicebell'.

Temperature (˚C)	Dry weight (g)	Flower diameter (cm)	Petal number
36	0.25 a[z]	3.7 a	19.6 a
40	0.25 a	3.4 a	19.4 a
44	0.23 b	2.7 b	16.5 b

[z]Tukey's HSD test at α= 0.05. Similar letters indicate differences are not significant.

'RIPhud'

The results from Dunnett's test showed no or little difference between the heat treatments and the control for dry weight, petal number or flower diameter (Table 17). There were no significant effects of the temperature x duration factorial treatments on any floral parameters measured on plants of 'RIPhud' (Table 18).

Table 17 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters of the rose 'RIPhud'.

Temperature (˚C)	Duration (h)	Dry weight (g)	Flower diameter (cm)	Petal number
control	N	0.45	8.2	8.6
36	1	0.41NS[z]	7.5 NS	7.6 NS
	3	0.45 NS	7.4 NS	8.0 NS
	5	0.44 NS	7.4 NS	8.1 NS
40	1	0.43 NS	6.6*	8.1 NS
	3	0.43 NS	7.5 NS	8.3 NS
	5	0.45 NS	7.1 NS	9.1 NS
44	1	0.38 NS	6.9 NS	8.1 NS
	3	0.41 NS	7.1 NS	8.8 NS
	5	0.41 NS	7.3 NS	7.8 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 18 Two-way ANOVA (F-values) of the effects of temperature and duration for three floral parameters of the rose 'RIPhud'.

Source	Dry weight (g)	Flower diameter (cm)	Petal number
Temperature	2.6 NS[z]	1.1 NS	1.6 NS
Duration	1.2 NS	0.7 NS	0.9 NS
Temp.× Duration	0.2 NS	0.6 NS	1.3 NS

[z]NS = No significance; *= Significance at the 5% level.

'Meipeporia'

The flowers on plants treated at 44 ˚C for 1 or 5 hours had less dry weight than the controls, but no significant effects were found among the temperature x duration factorial treatments (Table 19 and Table 20). Flower diameter was reduced by the 36˚C treatment for 1 hour, but the difference was very small. There was an interaction of temperature and duration on flower diameter but the differences between temperatures by duration were

either nonsignificant or resulted in an increase in flower diameter (Table 20, Figure 6). The biggest significant difference between two mean flower diameters was only 1.1 cm so that an effect of these factors appears to be negligible.

Table 19 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters of the rose 'Meipeporia'.

Temperature (˚C)	Duration (h)	Dry weight (g)	Flower diameter (cm)	Petal number
control	N	0.48	5.8	31.3
36	1	0.37 NS[z]	4.7*	25.1 NS
	3	0.45 NS	5.8 NS	38.0 NS
	5	0.39 NS	5.4 NS	29.3 NS
40	1	0.38 NS	5.8 NS	27.3 NS
	3	0.38 NS	5.6 NS	28.3 NS
	5	0.41 NS	6.0 NS	30.8 NS
44	1	0.32*	5.2 NS	26.6 NS
	3	0.41 NS	5.3 NS	29.1 NS
	5	0.29*	5.4 NS	25.6 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 20 Two-way ANOVA (F-values) of the effects of temperature and duration for three floral parameters of the rose 'Meipeporia'.

Source	Dry weight (g)	Flower diameter (cm)	Petal Number
Temperature	1.5 NS[z]	6.9*	0.9 NS
Duration	1.5 NS	2.5 NS	2.2 NS
Temp.× Duration	0.7 NS	3.4*	1.3 NS

[z]NS = No significance; *= Significance at the 5% level.

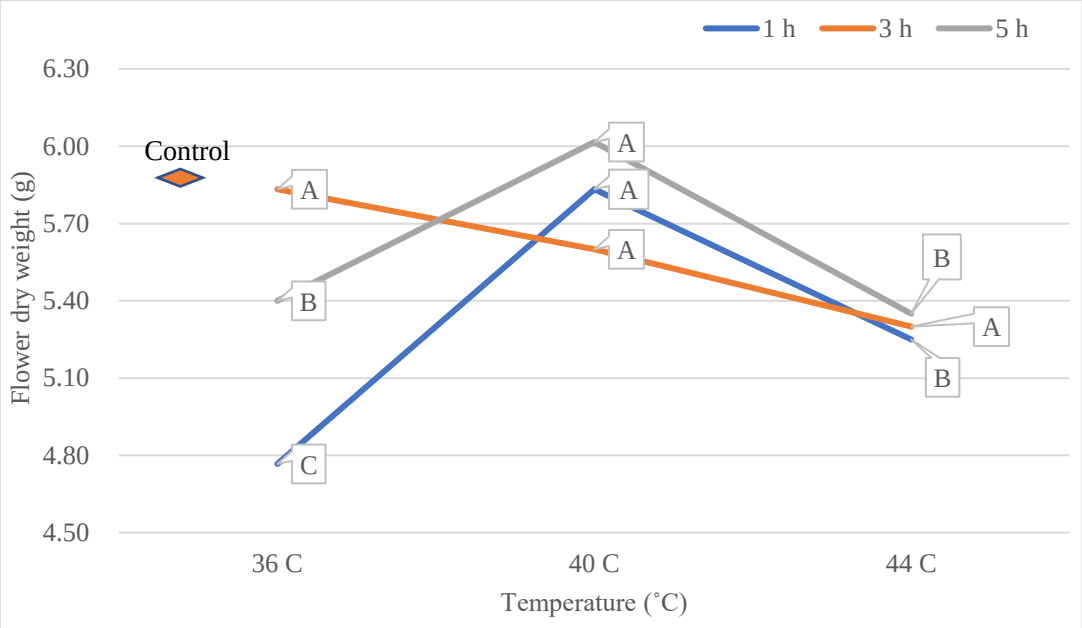

Figure 6 Means of temperature by duration for flower diameter of the rose 'Meipeporia'. Different letters refer to significantly different means within each duration (three points of the same line).

'Morden Blush'

Compared with control plants, no differences were found for dry weight and flower diameter in response to the heat treatments (Table 21). However, dry weight was significantly influenced by temperature when considering the factorial treatment analysis with the 44 ˚C treatments resulting in significantly lower flower dry weight in comparison to the 36 ˚C treated plants (Table 22 and Table 23). Flower diameter was unaffected. Petal number was lower than the control on plants treated at 44 ˚C for 1 hour (Table 21). The factorial analysis showed that petal number decreased as temperature increased (Table 22 and Table 23).

Table 21 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters of the rose 'Morden Blush'.

Temperature (˚C)	Duration (h)	Dry Weight (g)	Flower Diameter (cm)	Petal number
control	N	0.43	5.0	41.8
36	1	0.49 NS[z]	5.7 NS	41.6 NS
	3	0.41 NS	5.0 NS	40.8 NS
	5	0.42 NS	6.2 NS	39.3 NS
40	1	0.38 NS	4.8 NS	29.8 NS
	3	0.39 NS	4.9 NS	32.1 NS
	5	0.42 NS	5.1 NS	40.8 NS
44	1	0.38 NS	4.9 NS	26.8*
	3	0.39 NS	5.2 NS	30.6 NS
	5	0.35 NS	5.0 NS	41.8 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 22 Two-way ANOVA (F-values) of the effects of temperature and duration for three floral parameters of the rose 'Morden Blush'.

Source	Dry weight (g)	Flower diameter (cm)	Petal Number
Temperature	5.5*[z]	3.4*	6.0*
Duration	0.5 NS	0.7 NS	2.4 NS
Temp.× Duration	1.7 NS	1.2 NS	1.2 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 23 The effect of temperature on three floral parameters (means) on the rose 'Morden Blush'.

Temperature (˚C)	Dry weight (g)	Flower diameter (cm)	Petal number
36	0.44 a[z]	5.6 b	40.6 a
40	0.40 a	4.9 a	34.3 ab
44	0.37 b	5.0 ab	31.1 b

[z]Tukey's HSD test at α= 0.05. Similar letters indicate differences are not significant.

'RADrazz'

The dry weight of 'RADrazz' was reduced by 3 or 5 hours at 40 ˚C and also at 44 ˚C regardless of duration when compared to the control (Table 24). For the factorial analysis,

there was a significant interaction of temperature × duration (Table 25). For the 1 h duration treatments dry weight after the 36 ˚C treatment was not different than the response to 44 ˚C. Three hours at 44 ˚C resulted in lower dry weight than three hours at 36 ˚C. And five hours at 40 and 44 ˚C resulted in lower dry weight than five hours at 36 ˚C. Thus, three hours at the highest temperature or 5 hours at the two highest temperatures resulted in decreased dry weight in comparison to exposure to the lowest temperature (Figure 7). The flower diameter was reduced when compared to the control by some treatments, but there was no pattern and the differences were small (Table 24). No significant effects were found for the factorial analysis (Table 25). The petal number was not affected by temperature or duration (Tables 24 and 25).

Table 24 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters of the rose 'RADrazz'.

Temperature (˚C)	Duration (h)	Dry Weight (g)	Flower Diameter (cm)	Petal number
control	N	0.42	6.7	9.3
36	1	0.36 NS[z]	6.2 NS	9.8 NS
	3	0.39 NS	6.0*	8.7 NS
	5	0.39 NS	6.2 NS	9.5 NS
40	1	0.37*	5.9*	9.3 NS
	3	0.33*	5.7*	8.8 NS
	5	0.25*	6.3 NS	9.0 NS
44	1	0.31*	6.1 NS	8.8 NS
	3	0.28*	6.0 NS	9.0 NS
	5	0.28*	5.9*	8.0 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 25 Two-way ANOVA (F-values) of the effects of temperature and duration for three floral parameters of the rose 'RADrazz'.

Source	Dry weight (g)	Flower diameter (cm)	Petal Number
Temperature	23.1*[z]	0.4 NS	2.7 NS
Duration	6.4*	0.3 NS	1.9 NS
Temp.× Duration	6.9*	0.7 NS	1.7 NS

[z]NS = No significance; *= Significance at the 5% level.

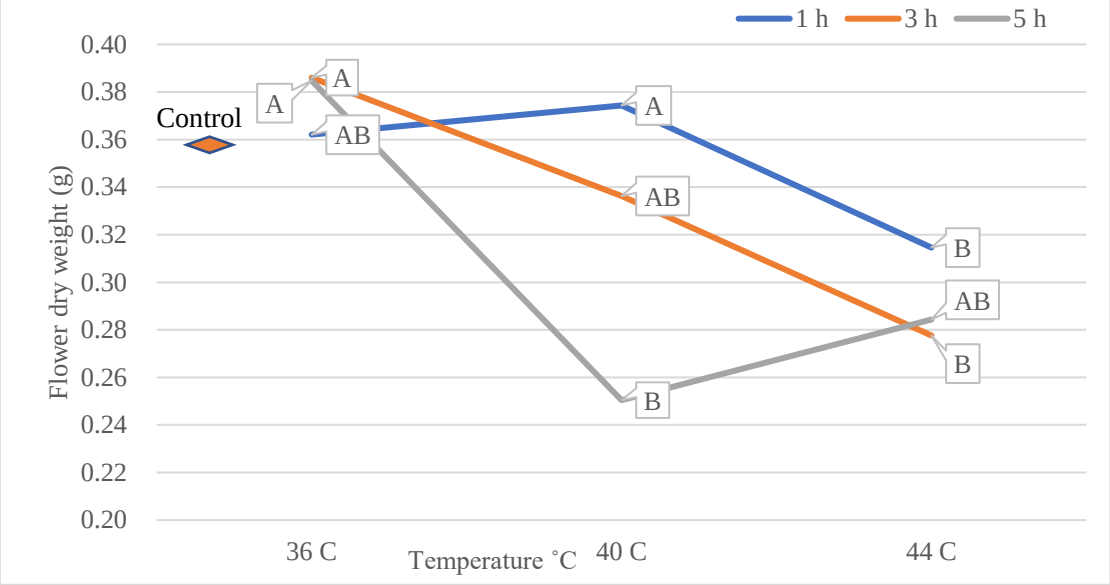

Figure 7 Two-way ANOVA of temperature and duration on flower dry weight of the rose 'RADrazz'. Different letters refer to significantly different means within each duration (three points of the same line).

'RADtko'

The control and treatment groups had no differences for all three floral parameters and no factorial effects were observed (Table 26, Table 27).

Table 26 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters of the rose 'RADtko'.

Temperature (˚C)	Duration (h)	Dry Weight (g)	Flower Diameter (cm)	Petal number
control	N	0.52	6.2	27.7
36	1	0.43 NS[z]	5.5 NS	27.5 NS
	3	0.47 NS	5.5 NS	26.3 NS
	5	0.39 NS	5.4 NS	23.7 NS
40	1	0.42 NS	5.7 NS	27.5 NS
	3	0.43 NS	5.4 NS	28.0 NS
	5	0.46 NS	6.2 NS	28.0 NS
44	1	0.43 NS	5.3 NS	27.0 NS
	3	0.44 NS	5.5 NS	27.5 NS
	5	0.45 NS	6.1 NS	26.0 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 27 Two-way ANOVA (F-values) of the effects of temperature and duration for three floral parameters on the rose 'RADtko'.

Source	Dry weight (g)	Flower diameter (cm)	Petal Number
Temperature	0.1 NS[z]	0.6 NS	1.6 NS
Duration	0.4 NS	1.8 NS	1.1 NS
Temp.× Duration	0.6 NS	1.0 NS	0.7 NS

[z]NS = No significance; *= Significance at the5% level.

'Winnipeg Parks'

Flower dry weight was reduced by treatment for 3 or 5 hours at 36 ˚C, 1 hour at 40 ˚C, and by 44 ˚C regardless of duration when compared to the control (Table 28). The interaction of temperature × duration was found in the factorial analysis with dry weight generally decreasing with increasing temperature with the strongest effect at 44 ˚C (Table 29, Figure 8). Treatment at 44 ˚C reduced petal number when compared to the control regardless of duration and the factorial analysis revealed the petal number was reduced as

temperature increased with no interaction with duration (Table 28, Table 29, and Table 30).

Flower diameter was not affected in this cultivar (Table 28, Table 29, and Table 30).

Table 28 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters of the rose 'Winnipeg Parks'.

Temperature (˚C)	Duration	Dry Weight	Flower Diameter	Petal number
control	N	0.67	7.9	16.8
36	1	0.63[z]	7.8 NS	15.3 NS
	3	0.54*	7.3 NS	14.0*
	5	0.54*	7.0 NS	15.8 NS
40	1	0.47*	7.6 NS	15.1 NS
	3	0.59 NS	8.1 NS	15.6 NS
	5	0.56 NS	7.4 NS	15.0 NS
44	1	0.43*	7.7 NS	13.3*
	3	0.37*	7.3 NS	13.3*
	5	0.34*	7.4 NS	13.8*

[z]NS = No significance; *= Significance at the 5% level.

Table 29 Two-way ANOVA (F-values) of the effects of temperature and duration for three floral parameters of the rose 'Winnipeg Parks'.

Source	Dry weight	Flower diameter	Petal Number
Temperature	35.2*[z]	1.1 NS	10.7*
Duration	0.6 NS	2.7 NS	0.8 NS
Temp.× Duration	4.7*	1.6 NS	1.6 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 30 Averages for floral parameters at different temperatures of 'Winnipeg Parks'.

Temperature (˚C)	Dry weight (g)	Flower diameter (cm)	Petal number
36	0.57 a[z]	7.4 a	15.1 a
40	0.54 a	7.7 a	15.2 a
44	0.38 b	7.5 a	13.5 b

[z]Tukey's HSD test at α= 0.05. Similar letters indicate differences are not significant.

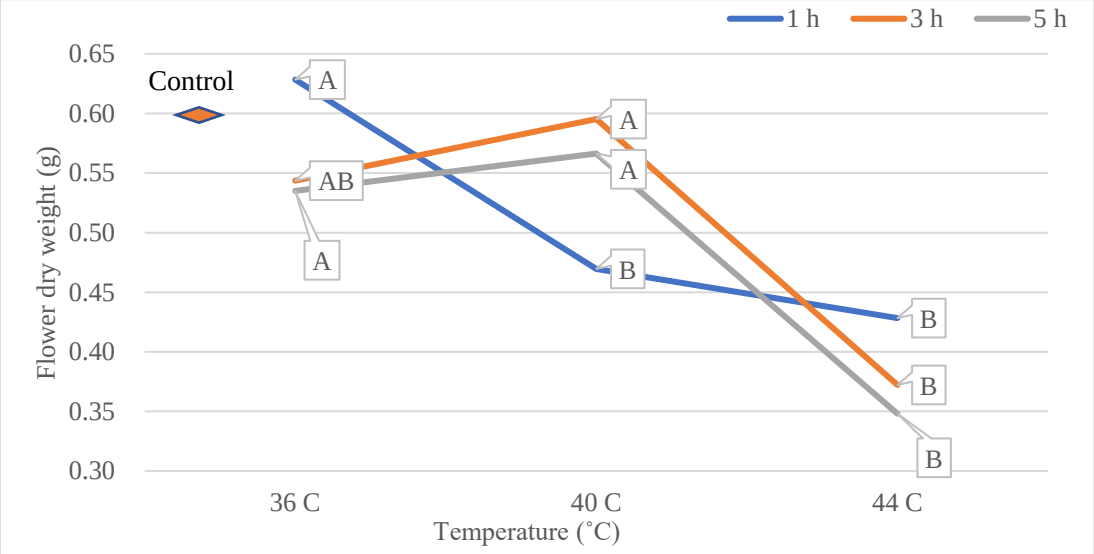

Figure 8 Means of temperature by duration for flower diameter of the rose 'Winnipeg Parks'. Different letters refer to significantly different means within each duration (three points of the same line).

'ZLEMarianne Yoshida'

Dry weight was reduced by 40 and 44 ˚C when compared to the control (Table 31). The factorial analysis showed a significant main effect of temperature with dry weight decreasing with increasing temperature (Table 32, Table 33). The flower diameter of the control was not different from treated plants, but the effect of temperature was significant in the factorial analysis showing a reduction with increasing temperature, though the differences were very small (Table 32 and Table 33). Petal number was not influenced by the temperature and duration treatments (Table 31, Table 32 and Table 33).

Table 31 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters of the rose 'ZLEMarianne Yoshida'

Temperature (˚C)	Duration (h)	Dry Weight (g)	Flower Diameter (cm)	Petal number
control	N	0.17	2.9	70.3
36	1	0.16 NS[z]	2.6 NS	68.0 NS
	3	0.15 NS	3.1 NS	64.6 NS
	5	0.16 NS	2.8 NS	68.5 NS
40	1	0.13*	2.9 NS	70.1 NS
	3	0.13*	2.9 NS	62.6 NS
	5	0.13*	3.1 NS	62.6 NS
44	1	0.11*	2.6 NS	68.0 NS
	3	0.10*	2.7 NS	64.6 NS
	5	0.10*	2.8 NS	65.3 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 32 Two-way ANOVA (F-values) of the effects of temperature and duration for three floral parameters of the rose 'ZLEMarianne Yoshida'.

Source	Dry weight (g)	Flower diameter (cm)	Petal Number
Temperature	42.9*[z]	4.4*	1.9 NS
Duration	0.4 NS	0.4 NS	1.6 NS
Temp.× Duration	0.2 NS	1.0 NS	1.9 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 33 The effect of temperature on three floral parameters (means) on the rose 'ZLEMarianne Yoshida'.

Temperature (˚C)	Dry weight (g)	Flower diameter (cm)	Petal number
36	0.16 a[z]	2.9 a	68.5 a
40	0.13 b	2.9 a	65.1 a
44	0.10 c	2.7 b	66.0 a

[z]Tukey's HSD test at α= 0.05. Similar letters indicate differences are not significant.

Bud size comparison of two cultivars

No visible leaf or peduncle was damaged after two weeks of heat treatments, but paler petal color of 'CHEwnicebell' was observed during collection of floral parameters. The analysis of variance of 4 factors (cultivar, temperature, duration, and bud size) were conducted, and the results indicated significant differences among cultivars on all three floral parameters.

'CHEwnicebell'

The dry weight, flower diameter and petal number of 2 mm buds were compared with the control (Table 34). The dry weight and flower diameter are significantly different from the control for all treatments, while petal number was not affected by temperature or duration treatments in comparison to the control (Table 34). For the factorial analysis, the size and temperature affected all three floral parameters with no interaction (Table 35). The size comparison according to t-test indicated the 4-mm buds larger in all aspects than flowers treated at the 2 mm stage (Table 36). All parameters were decreased by temperature (Table 37).

Table 34 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters on the rose 'CHEwnicebell' treated when buds were 2 mm in diameter.

Temperature (˚C)	Duration (h)	Dry Weight (g)	Flower Diameter (cm)	Petal number
control	N	0.28	3.8	17.0
36	1	0.22*[z]	2.8*	13.5 NS
	3	0.22*	3.1*	13.0 NS
	5	0.24*	3.1*	15.3 NS
40	1	0.23*	2.8*	16.6 NS
	3	0.23*	3.1*	15.1 NS
	5	0.23*	2.8*	15.8 NS
44	1	0.22*	2.6*	15.8 NS
	3	0.23*	2.4*	13.6 NS
	5	0.21*	2.4*	12.8 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 35 Three-way ANOVA (F-values) of the effects of bud size, temperature and duration for three floral parameters of the rose 'CHEwnicebell'.

Source	Dry weight (g)	Flower diameter (cm)	Petal Number
Temperature	7.2*[z]	26.9*	5.7*
Duration	0.4 NS	1.7 NS	0.6 NS
Temperature × duration	2.4 NS	1.6 NS	1.7 NS
Bud size	26.9*	29.0*	43.7*
Temperature × size	0.4 NS	2.2 NS	2.7 NS
Duration × size	0.1 NS	0.2 NS	0.4 NS
Temperature ×duration × size	0.9 NS	0.5 NS	0.1 NS

[z]NS = No significance; *= Significance at the 5% level.

Table 36 The effects of bud size on floral parameters of 'CHEwnicebell'.

Bud size (mm)	Dry weight (g)	Flower diameter (cm)	Petal number
2	0.23 b[z]	2.9 b	14.9 b
4	0.25 a	3.4 a	18.7 a

[z]Student t-test at α= 0.05. Similar letters indicate differences are not significant.

Table 37 The effect of temperature on three floral parameters (means) on the rose 'CHEwnicebell'.

Temperature (˚C)	Dry weight (g)	Flower diameter (cm)	Petal number
36	0.24 a[z]	3.4 a	17.6 a
40	0.24 a	3.2 a	16.8 a
44	0.23 b	2.6 b	15.3 b

[z] Tukey's HSD test at α= 0.05. Similar letters indicate differences are not significant.

'RADtko'

The dry weight and petal number of 'RADtko' showed no difference from control group, and the analysis of variance showed no effects of temperature, duration or bud size (Table 38 and Table 39). The flower diameter at 44 ˚C for 5 h was less than the control, but other treatments were not and temperature treatments did not affect petal number in comparison to the control (Table 38). Temperature, duration, and bud size had no effect on any of the floral parameters measured (Table 39).

Table 38 Mean temperature and duration treatment effects with each treatment compared to the control using Dunnett's test for three floral parameters of the rose 'RADtko'.

Temperature (˚C)	Duration (h)	Dry Weight (g)	Flower Diameter (cm)	Petal number
control	N	0.48	6.2	24.4
36	1	0.47 NS[z]	6.3 NS	25.5 NS
	3	0.39 NS	5.6 NS	26.6 NS
	5	0.39 NS	5.3 NS	22.8 NS
40	1	0.41 NS	5.6 NS	23.6 NS
	3	0.37 NS	5.7 NS	22.6 NS
	5	0.42 NS	5.4 NS	26.0 NS
44	1	0.42 NS	5.7 NS	25.3 NS
	3	0.44 NS	5.3 NS	25.6 NS
	5	0.40 NS	5.2*	24.5 NS

[z] NS = No significance; *= Significance at the 5% level.

Table 39 Three-way ANOVA (F-value) of the effects of bud size, temperature and duration for three floral parameters of the rose ‘RADtko’.

Source	Dry weight	Flower diameter	Petal Number
Temperature	0.0 NS[z]	0.1 NS	0.4 NS
Duration	0.0 NS	0.3 NS	1.1 NS
Temperature × duration	0.0 NS	0.0 NS	2.1 NS
Bud size	0.0 NS	1.1 NS	1.0 NS
Temperature × size	0.0 NS	0.5 NS	1.7 NS
Duration × size	0.0 NS	2.0 NS	0.2 NS
Temperature ×duration × size	0.0 NS	0.7 NS	0.4 NS

[z] NS = No significance; *= Significance at the 5% level.

Discussion and conclusion

The different cultivars tested responded to the brief temperature treatments with a range of responses. The comparisons of each treatment with the control and the results of the two-way ANOVA for the factorial combination of temperature × duration treatments for each cultivar were used to characterize the floral tolerance of each cultivar by assigning each one to a heat tolerance category (Table 40). For the floral parameters measured, dry weight exhibited the highest number of differences among all the cultivars when each individual temperature × duration treatment was compared to the control with Dunnett’s test (Table 40). This parameter was thus used as the primary means for assigning cultivars to a category. ‘RADtko’ and ‘RIPhud’ were assigned to the Heat Tolerant category as the flowers exhibited no differences between the temperature × duration (heat) treatments and the control for dry weight and there was no significant ANOVA temperature × duration factor effects for any of the floral parameters.

‘Champlain’ and ‘Meipeporia’ were assigned to the Moderately Heat Tolerant

category because there were two differences between the heat treatments and the control for dry weight and there was at least one floral parameter showing an effect of the ANOVA factors. ‘Morden Blush’ was included in this category because there were no differences between the heat treatments and the control for dry weight, but it couldn’t be considered for the Heat Tolerant category due to the presence of factor effects for all the floral parameters. ‘RADrazz’ was placed in this category despite the high number of differences between the heat treatments and the control for dry weight because there were no factor effects for flower diameter and petal number.

‘Winnipeg Parks’ was assigned to the Moderately Heat Sensitive category due to the six differences between the heat treatments and the control for dry weight and the factor effects seen for petal number. ‘CHEwnicebell’ and ‘ZLEMarianne Yoshida’ were placed in the Heat Sensitive category due to the nine differences for each cultivar between the heat treatments and the control for dry weight and the factor effects for one or two other floral parameters in addition to the factor effects for dry weight.

After characterizing the floral heat tolerance of the cultivars in the present study, a comparison to the heat tolerance status of the same cultivars as determined in previous field evaluations and presented in Table 9 does not all match up. ‘RADtko’, ‘RIPhud’, ‘Meipeporia’, and ‘RADrazz’ were considered Heat Tolerant based on field evaluations and were categorized for floral heat tolerance as either Heat Tolerant or Moderately Heat Tolerant. ‘Winnipeg Parks’ and CHEwnicebell’ were considered Heat Sensitive based on field evaluations and were categorized for floral heat tolerance as either Moderately Heat Sensitive or Heat Sensitive. However, ‘Champlain’ and ‘Morden Blush’ were considered

Heat Sensitive based on field evaluations but were categorized for floral heat tolerance as Moderately Heat Tolerant. Also, 'ZLEMarianne Yoshida' was considered Heat Tolerant based on field evaluations but was categorized for floral heat tolerance as Heat Sensitive. The field studies used for the original heat tolerance considerations (Table 9) relied on response variables based on whole plant evaluations including landscape ratings, percentage of flower cover, disease incidence ratings, and percentage of defoliation (Byrne et al., 2010; Harp et al., 2019; Mackay et al., 2008; Mangandi et al., 2013; Zlesak et al., 2017). Clearly, the response of the floral parameters measured in the current studies as a response to brief high temperature treatments reveal aspects of floral heat tolerance that are not apparent in a field study based on whole plant response characteristics. For some cultivars these responses are similar in reference to heat tolerance, but for others this is not the case. A deeper understanding of floral responses to high temperatures and how these characteristics are combined with other aspects of whole plant heat tolerance in garden roses would be advantageous to efforts for improved cultivar development. Of course, there are other aspects of plant growth that are involved in heat tolerance. For example, the physiological mechanism of rice (*Oryza sativa* L.) against heat stress was studied and the high activity of the root system indicated the ability to cope with heat stress (Yun-Ying et al., 2008). More measurements of the growth conditions of plants are suggested to test for heat tolerance.

Table 40 Characterization of floral heat tolerance for 9 cultivars of garden roses based upon the floral parameters affected by a factorial combination of temperature and duration treatments given as a brief shock treatment.

		Floral parameter measurement affected by temperature and duration treatments[z]		
Heat Tolerance Category	Cultivar	Dry Weight (g)	Flower Diameter (cm)	Petal number
Heat Tolerant				
	'RADtko'	NS[y] (0)[x]	NS (0)	NS (0)
	'RIPhud'	NS (0)	NS (1)	NS (0)
Moderately Heat Tolerant				
	'Champlain'	* (2)	* (0)	NS (0)
	'Meipeporia'	NS (2)	* (1)	NS (0)
	'Morden Blush'	* (0)	* (0)	* (1)
	'RADrazz'	* (5)	NS (4)	NS (0)
Moderately Heat Sensitive				
	'Winnipeg Parks'	* (6)	NS (0)	* (4)
Heat Sensitive				
	'CHEwnicebell'	* (9)	* (5)	* (2)
	'ZLEMarianne Yoshida'	* (9)	* (0)	NS (0)

[z]Treatments consisted of the factorial combination of temperature at 36, 40, or 44 ˚C and duration at 1, 3, or 5 hours.

[y]NS= Parameter not affected by temperature x duration treatments. *= Parameter affected by temperature × duration treatments.

[x]The number in parentheses is the number of each individual temperature × duration treatments that were significantly less than the control when tested with Dunnett's test.

When considering the response of floral parameters measured to temperature and duration treatments, temperature appeared to serve as a more important factor than duration among all cultivars. For example, all the floral parameters measured for the cultivars categorized as Heat Sensitive except petal number for ‘ZLEMarianne Yoshida’ were affected significantly by treatment at 44˚C regardless of duration. This was comparable to previous research which used a heat shock treatment at 44˚C for 1 hour to study the effect on the same floral parameters used in the current study for progeny from 10 breeding populations of garden roses (Liang et al., 2017a). Liang et al. (Liang et al.) did not see a strong enough response to the 1-hour treatment used to consider it useful for breeding purposes, but suggested using the high temperature for longer or even a lower temperature for longer durations to enable the results to be more useful. Indeed, the interaction of temperature and duration in the present studies where the longer durations and higher temperatures produced significant reductions in floral measurements appears to support this suggestion. This held true for responses exhibited by cultivars categorized as more heat tolerant such as for dry weight of ‘RADrazz’, ‘Champlain’, and for flower diameter of ‘Meipeporia’ flowers.

Under a relatively controlled environment as greenhouse and heat chamber, the floral parameters measured in this project appear to be important for determining floral heat tolerance. The petal number of each flower is genetically controlled by each genotype of rose and has been found to be affected by the ambient environment (Liang et al., 2017b). However, petal number was the parameter measured in the current study that was least

affected by the temperature treatments. The plants were treated three weeks after cut back to synchronize new growth of flowering shoots, which may indicate that petals were already developed before the heat treatment was applied. While studying the effects of light and temperature on cut flower development of *Rosa* 'Baccara', the sepals were found to start differentiating three weeks after cut back and petals started at four weeks after (Moe and Kristoffersen, 1968). Despite this, a brief heat treatment had an effect on some cultivars in the current study, but no doubt a longer period of high temperature during shoot development could have a stronger effect.

Flower dry weight has been used as a measure of rose floral heat tolerance in both field studies (Greyvenstein et al., 2015a; Liang et al., 2017a) and growth chamber studies (Greyvenstein et al., 2014; Greyvenstein et al., 2015; Liang et al., 2017b). In the current studies, all of the cultivars categorized as Moderately Heat Sensitive and Heat Sensitive had reduced flower dry weight in response to heat treatment indicating the importance of this character in determine flower heat tolerance in rose. Flower diameter has been used in one study of rose flower heat tolerance using a brief high temperature treatment (Liang et al., 2017a). In the same study, flower diameter was the only floral measurement to show a genotype by environment interaction. This and the fact that in the current study, flower diameter was affected by heat treatment in most of the cultivars in the susceptible categories indicate that it could be a useful measurement for the determination of floral heat tolerance in garden roses.

The response to high temperature was seen in cut rose production when flower dry weight on 'Kardinal' rose plants was found to decrease as the temperature increased from

18 ˚C to 30 ˚C (Shin et al., 2001). The stage of visible bud was also indicated as the most sensitive to heat treatment in a growth chamber for two weeks at 36/28˚C day/night in the study of two garden rose cultivars 'Belinda's Dream' and 'RADrazz', as more buds and flowers aborted than control plants treated at 24/17˚C day/night (Greyvenstein Ockert et al., 2014). Heat treatments at this most sensitive stage triggered flower abortion in the study just mentioned and others (Greyvenstein et al., 2015; Greyvenstein et al., 2019), but no flower abortion even at the heat treatment of 44 ˚C and 5 h was seen in the present study. The current work used plants with flower buds 4 mm in diameter for treatment instead of the 1-2 mm size used in the other studies just discussed. There was no difference between the response of the two bud sizes to high temperature treatments in the present study in regards to flower abortion or leaf damage, but only two cultivars were used for this comparison. Other cultivars may be more sensitive to heat when smaller bud sizes are treated.

The responses of floral parameters to the temperature and duration treatments used in the current studies have provided valuable insights into aspects of floral heat tolerance in garden roses. In conclusion, rose cultivars differed in their heat tolerance as measured by flower dry weight, flower diameter, and petal number. Exposure of plants with buds 4 mm in diameter to 44˚C for 3 or 5 h was the most effective treatment for determining floral heat tolerance for the cultivars studied.

CHAPTER IV

CONCLUSION

The work in this thesis was first studied the alteration of plant architecture by spent flower removal during the summer season on 4 cultivars of garden roses at two different locations. Secondly, the work was focused on the responses to short periods of time of heat treatments on garden roses in greenhouse environment, and also gives predictions of heat tolerance for these cultivars.

The effects of pruning and location in garden cultivars

Days to rebloom were not affected by the spent flower removal method in this study, although considered 'Belinda's Dream' had growth habits like hybrid tea and 'Bucbi' with a floribunda growth habit. Regardless of the factor of cultivar, plants in Overton had no difference by pruning but days to rebloom was shortened compared to plants in College Station. Thus, the location could be a stronger influence for days to rebloom than spent flower removal.

The primary shoot number was not affected by pruning, and plants in Overton had more primary shoot than in College Station. Secondary shoot number was reduced by spent flower removal in this study. These results showed that spent flower removal to the first five-leaflet leaf may not affect the primary shoot and secondary shoot number in practice.

In College Station, plants had more secondary shoots and tertiary shoots than plants in Overton. The average temperatures of these two locations were different as College Station has shorter freezing temperature months and higher temperatures all over the year. The effect of cultivar is significant at both locations. ‘Belinda’s Dream’ had fewer secondary shoots, tertiary shoots, and barely any quaternary shoot when compared to other cultivars. ‘Bucbi’, ‘RIPhud’ and ‘Meiggili’ had similar levels of shoot development.

Responses to heat treatments in garden cultivars

A series of responses to heat treatments were measured by floral parameters among cultivars. These cultivars could be categorized into four types: Heat Tolerant, Moderately Heat Tolerant, Moderately Heat Sensitive, and Heat Sensitive. Heat sensitive cultivars are ‘CHEwnicebell’ and ‘ZLEMarianne Yoshida’ had most of the plants that the highest number of heat treatments plants had a reduction of floral parameters. As for Moderately Heat Sensitive, ‘Winnipeg Parks’ decreased on dry weight and petal number, and also six groups of treatments had differences from the control. For Moderately Heat Tolerant cultivars, these cultivars had fewer floral parameters affected by heat treatments, and one parameter was reduced on different cultivars. ‘Meipeporia’ showed a reduction in flower diameter and ‘RADrazz’ had a reduction in flower dry weight. ‘Morden Blush’ had no difference when comparing each treatment with control, but the effects of the factors within treatments suggest this cultivar belongs to Moderately Heat Tolerant. ‘Champlain’ was also suggested as moderately heat tolerant as the dry weight

was reduced by 44 ˚C. ‘RIPhud’, and ‘RADtko’ were the most heat tolerant among all cultivars as no effect was found on all three floral parameters.

Flower dry weight, flower diameter, and petal numbers were used to evaluate rose heat tolerance in several studies (Chapter III), but the fewer dry weight was affected most by heat treatments in this experiment. In addition, temperatures and durations in this study are suggested at 44 ˚C and 3 or 5 hours for screening heat tolerant rose cultivars.

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