

## Factors affecting variation in the vase life response of waxflower cultivars (Myrtaceae: *Chamelaucium* Desf. and *Verticordia* spp. Desf.) tested under various vase solutions

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### ABSTRACT

The effects of genotype and vase solutions on the vase lives of waxflower cultivars were studied. The vase life of 16 cultivars derived from different genetic backgrounds showed a variation. The vase life of *Chamelaucium uncinatum* cultivars held in deionised water was generally the shortest, with four cultivars averaging 9.5 and 8.9 days for flowers and leaves while the vase lives of *C. uncinatum* × *megalopetalum* hybrids were on average 16.0 and 25.0 days for flowers and leaves, respectively. The hybrid ‘Southern Stars’ with *C. uncinatum* × *Verticordia plumosa* as parents had the longest flower vase life of 24.9 days, although another *Verticordia* × *Chamelaucium* had a 9.5-day flower vase life and other hybrids of the cultivars of *C. uncinatum* and *Verticordia grandis* Desf. (‘WX73’), *C. sp. Gingin Marchantii* (‘WX97’) and *C. floriferum* (‘Lady Stephanie’) as a parent had intermediate to short vase lives of 11.4 to 15.5 days. The cultivars responded most to 8-hydroxyquinoline sulphate (HQS) + sucrose or HQS + sucrose + silver thiosulphate (STS), being 1.5- to 1.6-folds higher than in deionized water. The cultivars showed a varied response to a vase solution of sucrose + HQS + STS, with which *C. uncinatum* vase life increased 1.9-fold compared to 1.7-fold for *C. megalopetalum*. Waxflowers were found to be susceptible to water stress, causing flowers to close and shortening vase life. On average for the 80 cultivar-vase solution combinations tested, flower vase life ended when the stems reached 75.5 ± 5% fresh weigh. Longer vase life cultivars had a greater ability of maintaining a water balance at or above 75% for longer.

Key words: 8-hydroxyquinoline sulphate, fresh weight, genotype, genetic variation, water balance, waxflowers

### INTRODUCTION

The vase life of cut flowers is highly dependent on the inheritance or genotype of the cultivars (Kende 1993). The vase lives of 17 *Anthurium andraeanum* Hort. cultivars varied from 14.0 days for ‘Evergreen’

to 49.0 days for ‘Cuba’, which was mainly dependent on the ability of cultivars to maintain positive water balance of cut stems (Elibox and Umaharan 2010). The vase life of *Gerbera jamesonii* Hooker cultivars was also variable (Tesi 1978), with some flowers lasting only 8.9 days while other flowers of

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the same clone lasted 16.0 days (Jong and Garretson 1985). Natural variation in the postharvest quality and organ retention of ornamental plants can often be related to differences in their response to ethylene sensitivity (Macnish et al. 2010), which for carnations (*Dianthus caryophyllus* L.) is heritable from their parents (Woltering et al. 1993, Onozaki et al. 2001). The benefits of sugar, HQS and STS in extending flower vase life and reducing flower abscission had been reported for many types of cut flowers including *Anthurium andraeanum* Hort. (Asrar 2012), *Gladiolus* spp. L. (Beura et al. 2011), *Dendrobium* spp. Swart (Dineshbabu et al. 2002), *C. uncinatum* (Joyce 1988, Seaton 2006b) and *C. megalopetalum* hybrid 'Bridal' and 'Albany Pearl' (Seaton 2005). Sugar provides carbohydrates as an energy source for flower respiration and reduces the induction of endogenous ethylene (Pun and Ichimura 2003) and also improves water balance (Halevy and Mayak 1974, Kuiper et al. 1995). HQS prevents the growth of microorganisms in xylem vessels maintaining water uptake and extending flower vase life (Asrar 2012). Combining HQS and sucrose increased the flower quality and vase life of gladiolus (Beura et al. 2011) and dendrobiums (Dineshbabu et al. 2002). STS has been used to reduce endogenous ethylene production, and consequently extended the vase life of waxflowers (Joyce 1993, Seaton 2005). STS also inhibits the microbial population, which causes the vascular

occlusion of stems (Asrar 2012). Vase life response varied with the addition of sugar to vase solutions for 'Golden Light', an inter-generic hybrid obtained between *Sandersonia aurantiaca* Hook. and *Littonia modesta* Hook., and was not improved (Eason et al. 2001) while it had a positive effect on the parents' vase life (Morgan et al. 2000). The vase life response of Asiatic hybrid lilies (*Lilium* L.) to STS was also dependent on genotype (van der Meulen-Muisers et al. 1999). We hypothesised the degree of vase life response in different genotypes of waxflowers depending on the water balance ability of the stems with several vase solutions. The aim of this study was to determine the degree of waxflowers' vase life response depending on the types of genotype derived from *Chamelaucium* and *Verticordia* crosses and the preserving solution containing combinations of sucrose, HQS and STS.

## MATERIAL AND METHODS

### Plant materials

The flowering stems of 16 cultivars derived from four species and hybrids of *Chamelaucium* and three hybrids of *Chamelaucium* and *Verticordia* (Tab. 1 and Fig. 1) were harvested in the field from an average of five mature bushes (approximately five year old) at Medina Research Station (32°13'18"S, 115°38'50"E) of the Department of Agriculture and Food Western Australia (DAFWA). All source plants

**Table 1.** The 16 cultivars used in the genetic variation study, their parents, petal colour and flower diameter

Cultivars	Parents	Petal colour	Flower diameter (cm)
Purple Pride	<i>C. uncinatum</i>	mid purple	1.7 ± 0.03
Mullering Brook	<i>C. uncinatum</i>	mid pink	1.2 ± 0.02
Monica's Blush	<i>C. uncinatum</i>	cream-white	1.4 ± 0.03
WX17	<i>C. uncinatum</i>	cream-white	1.8 ± 0.02
WX87	<i>C. uncinatum</i> × <i>C. megalopetalum</i>	cream-white	1.9 ± 0.02
Matilda	( <i>C. uncinatum</i> × <i>C. uncinatum</i> ) × <i>C. megalopetalum</i>	white	2.1 ± 0.02
Bridal Pearl	<i>C. megalopetalum</i> × <i>C. uncinatum</i>	cream-white	1.6 ± 0.02
Denmark Pearl	<i>C. megalopetalum</i> × <i>C. uncinatum</i>	cream-white	1.7 ± 0.02
Laura Mae Pearl	<i>C. megalopetalum</i> × <i>C. uncinatum</i>	cream-white	1.6 ± 0.01
Crystal Pearl	<i>C. megalopetalum</i> × <i>C. uncinatum</i>	cream-white	1.8 ± 0.02
WX102	<i>C. megalopetalum</i> × <i>C. uncinatum</i>	mid pink	1.9 ± 0.02
Jasper	<i>C. uncinatum</i> × <i>Verticordia plumosa</i>	light-mid pink	0.75 ± 0.01
Southern Stars	<i>C. uncinatum</i> × <i>Verticordia plumosa</i>	very-light pink	0.65 ± 0.01
WX73	( <i>C. uncinatum</i> × <i>Verticordia grandis</i> ) × <i>Verticordia grandis</i>	very light red	1.9 ± 0.01
WX97	<i>C. sp. Gingin</i> × ( <i>C. uncinatum</i> × <i>C. uncinatum</i> )	cream-white	1.1 ± 0.02
Lady Stephanie	<i>C. floriferum</i> × <i>C. uncinatum</i>	white-light pink	1.2 ± 0.01

Data are the mean ± standard error (n = 10) for opened flowers with a nectariferous hypanthium



**Figure 1.** Waxflower cultivars used in the study: (a) Purple Pride, (b) Mullering Brook, (c) Monica's Blush, (d) WX17, (e) WX87, (f) Matilda, (g) Bridal Pearl, (h) Denmark Pearl, (i) Laura Mae Pearl, (j) Crystal Pearl, (k) WX102, (l) Jasper, (m) Southern Stars, (n) WX73, (o) WX97 and Lady Stephanie

were cultivated using irrigation and fertigation best practices (Seaton and Poulish 2010). Flowering stems of approximately 70 cm were picked with 50–70% flowers open in the early morning, and the cut ends of stems were immediately placed upright in buckets of clean water, and then transported by air-conditioned vehicle at approximately 20°C to the postharvest laboratory of DAFWA at South Perth, taking about 35 min. At the laboratory the cut stems were randomly chosen and recut under water to 30 cm in length (measured from the cut ends to the most extreme opened-flower) for vase life treatments (Seaton and Joyce 1996, Seaton et al. 2010).

#### **Vase solutions**

The following vase solutions were used to test the vase life response of waxflower cultivars:

1. Deionised water (DI) (control)
2. 200 mg L<sup>-1</sup> 8-hydroxyquinoline sulphate (HQS)

3. 200 mg L<sup>-1</sup> 8-hydroxyquinoline sulphate (HQS) and silver thiosulphate (STS) (applied as a 20-min pulse at 4 mM)
4. 58.48 mmol sucrose and 200 mg L<sup>-1</sup> 8-hydroxyquinoline (HQS)
5. 58.48 mmol sucrose (sucrose) and 200 mg L<sup>-1</sup> 8-hydroxyquinoline sulphate (HQS) and silver thiosulphate (STS) (applied as a 20-min pulse at 4 mmol).

#### **Silver thiosulphate pulsing**

Harvested stems were recut under water at a length of 60 cm, and then stood in a 4 mmol STS solution for 20 min. at 20°C. Immediately after pulsing, stem ends were rinsed under a running tap water and then stems stood with cut ends in buckets of clean water. Buckets containing pulsed-stems were placed in cold storage at approximately 5°C for 24 h in order to redistribute Ag<sup>+</sup> in the flower stems and then recut under water to 30 cm length for trials.

### Assessment of vase life

The end of flower vase life was recorded when 50% of the opened flowers fully closed or showed petal damage. For cultivars where flowers dropped before closing, the end of vase life was determined when 50% of the opened flowers had dropped. Leaf vase life was determined when 50% of the leaves were fully desiccated or yellow.

### Assessment of the relationship between flower vase life, stem fresh weight and days to stem fresh weight reaching 75% of initial weight

Stem fresh weight was recorded daily until the end of flower vase life and expressed as a percentage of initial fresh weight. Analysing stem fresh weight at the end of flower vase life showed that flowers ended vase life when stem fresh weight reaching 75.5% of the initial weight. Thus, the day for stem fresh weight reaching 75% of initial weight was determined to analyse the relationship between flower vase life and the day for stem fresh weight at 75% of initial weight. Vase life was recorded in an air-conditioned room at  $20 \pm 2^\circ\text{C}$ ,  $60 \pm 10\%$  RH with a 12 h photoperiod. The light flux densities are  $8 \mu\text{m m}^{-2} \text{s}^{-2}$ .

### Statistical design and analysis

The experiments were arranged in a completely randomized design with five treatments per cultivar, and each treatment was replicated eight times, excluding 'WX73' where the replication was five times. The vase life of the flowers and leaves from the treatments' effect was analysed by two-way ANOVA using the statistical package Genstat XV (Lawes Agricultural Trust, Rothamsted Experimental station, UK). Replication was eight-fold consisting of a single stem in individual vases. Treatment means were compared by LSD at  $p = 0.05$  and standard errors of the mean ( $\pm$  SE) were shown as appropriate. When possible, mean comparisons were made using Duncan's Multiple Range Test.

## RESULTS

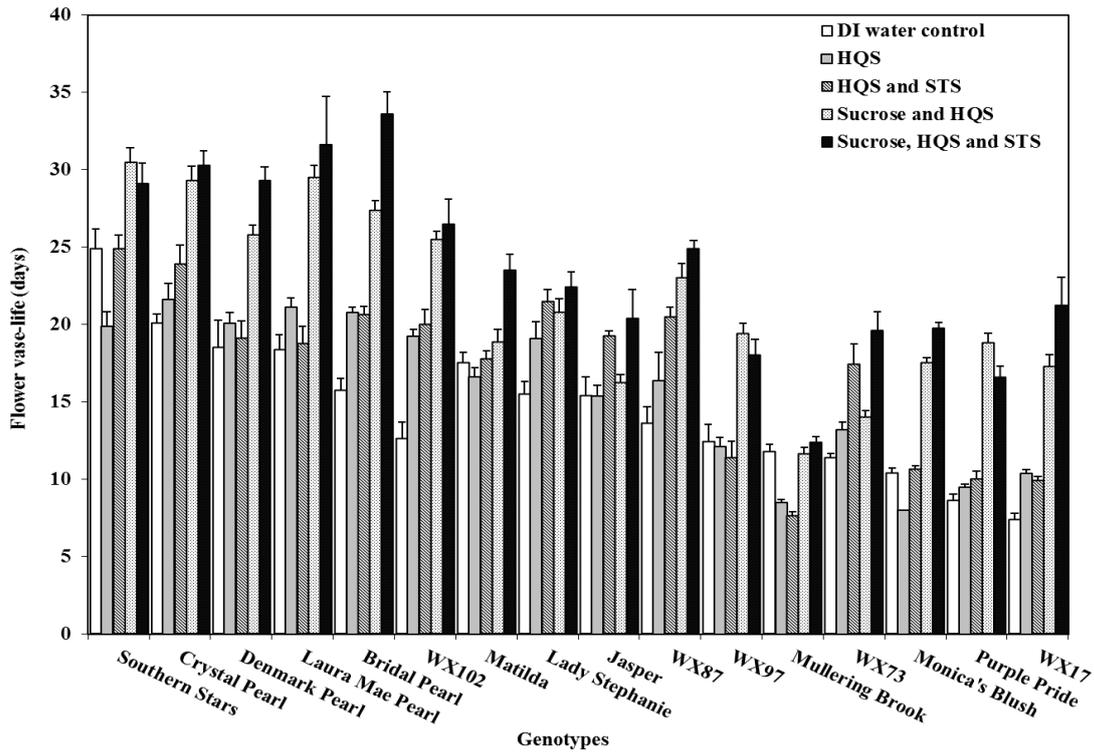
### Effect of genotype in DI water

There was a significant ( $p = 0.05$ ) difference in the vase life of flowers and leaves between cultivars ranging from 7.4 to 24.9 days for flowers and 5.5 and 21.5 days for leaves. The vase life of the cultivars of *C. uncinatum* was the shortest, at less than 12.0 days for flowers (ranging from 7.4 days for 'WX17' to 11.8 days for 'Mullering Brook') and less than 11.0 days for leaves (ranging from

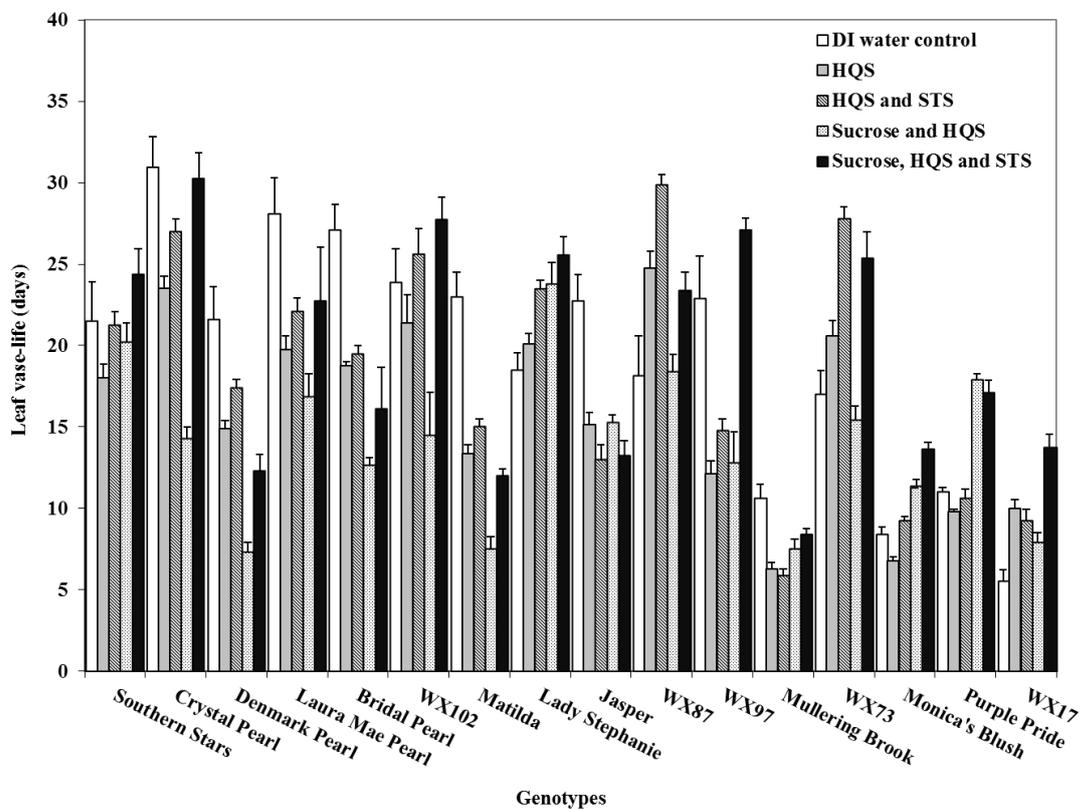
5.5 days for 'WX17' to 11.0 days for 'Purple Pride'). For *C. megalopetalum* hybrids, vase life was longer than 12 days for flowers (ranging from 12.6 days for 'WX102' to 20.1 days for 'Crystal Pearl') and longer than 18.0 days for leaves (ranging from 18.1 days for 'WX87' to 31.0 days for 'Crystal Pearl'). Within the cultivars of *C. uncinatum* and *C. megalopetalum*, vase life was significantly higher for 'Crystal Pearl', 'Laura Mae Pearl' and 'Bridal Pearl', all of which had a vase life of 27.0 to 31.0 days, while the other *C. uncinatum* and *C. megalopetalum* of 'Denmark Pearl', 'Matilda', 'WX87' and 'WX102' had a 5.0 to 9.0 day shorter vase life. Similarly, the leaves of the *C. megalopetalum* hybrids 'WX87' and 'WX102' had a significantly ( $p = 0.05$ ) shorter vase life of 12.0 to 13.0 days compared to 'Crystal Pearl', 'Denmark Pearl', 'Laura Mae Pearl', 'Matilda' and 'Bridal Pearl', with 16.0 to 20.0 days vase life (Fig. 3). For three *Verticordia* hybrids, flower vase life showed a similar range to *C. megalopetalum* hybrids and ranged from 11.4 days for 'WX73', a *C. uncinatum*  $\times$  *V. grandis* hybrid, to 24.9 days for 'Southern Stars', a *Chamelaucium*  $\times$  *V. plumosa* hybrid, and the vase life of leaves ranged from 17.0 days for 'WX73' to 31.5 days for 'Southern Stars' (Figs 2 and 3). The *Verticordia* hybrid of 'Jasper' with a similar parentage as 'Southern Stars' in contrast had a flower vase life that was 10 days shorter than 'Southern Stars' and a leaf vase life that was not significantly ( $p = 0.05$ ) different to 'Southern Stars'. However, vase life was longer for the *C. floriferum* hybrid 'Lady Stephanie' than the *C. uncinatum* cultivars, with 15.5 days for flowers and 18.5 days for leaves and flower vase life was 12.4 days for the *C. sp.* *Gingin* hybrid 'WX97', similar to the *C. uncinatum* cultivars, while leaf vase life was longer and similar to *C. megalopetalum* hybrids of 22.9 days.

### Effect of vase solutions – flower vase life

Compared to DI water as a vase solution, sucrose, HQS and STS significantly ( $p = 0.05$ ) extended flower vase life over all of the cultivars by 1.6-fold, followed by the vase solution of sucrose and HQS by 1.5-fold, whereas the vase solution of HQS and STS increased the vase life of cultivars by 1.2-fold and the vase solution of HQS was less effective and caused the vase life of flowers to decrease in six cultivars (Fig. 2). A vase solution of sucrose, HQS and STS was more effective in *C. uncinatum*, increasing vase life 1.8-fold compared to cultivars with *C. megalopetalum* as a parent (1.7-fold) and compared to cultivars with *C. sp.* *Gingin* (1.4-fold),



**Figure 2.** Vase life of flowers of cultivars held in various vase solutions and DI water as the control. LSD for genotype = 1.2 days, for vase solution = 0.7 day and for genotype × vase solution = 2.7 days by two-way analysis of variance at  $p = 0.05$ . Vertical bars are standard errors of the mean



**Figure 3.** Leaf vase life of cultivars held in various vase solutions and DI water as the control. LSD for genotype = 1.5 days, LSD for vase solution = 0.9 day and LSD for genotype × vase solution = 3.4 days by two-way analysis of variance at  $p = 0.05$ . Vertical bars are standard errors of the mean

*C. floriferum* (1.4-fold) or *Verticordia* (1.4-fold) as a parent. Cultivars with lower vase life tested in DI water had a larger response to vase solutions, with a flower vase life of 'WX17' increased by 2.9-fold in sucrose, HQS and STS and similarly a 2.5-fold increase in leaf vase life. 'Mullering Brook' was an exception and did not show a significant ( $p = 0.05$ ) response to sucrose, HQS and STS. The effect of vase solutions did not increase the vase life of the cultivar compared to the DI controls. The vase life of *C. uncinatum* cultivars was significantly ( $p = 0.05$ ) extended by 1.9-fold in the vase solution of sucrose, HQS and STS and by 1.7-fold in the vase solution of sucrose and HQS, but did not increase in vase solutions of HQS or HQS and STS. The vase life of cultivars with *C. megalopetalum* as another parent was extended by 1.7- and 1.6-fold in vase solutions of sucrose and HQS with and without STS respectively, but by 1.2-fold in HQS or HQS and STS vase solutions (Fig. 2). The vase life of cultivars with *Verticordia*, *C. sp. Gingin* 'WX97' and *C. floriferum* 'Lady Stephanie' as another parent was significantly ( $p = 0.05$ ) extended by 1.4-fold in the vase solution of sucrose, HQS and STS, while the vase solution of sucrose and HQS significantly ( $p = 0.05$ ) extended the flower vase life of 'WX97' by 1.5-fold, followed by the cultivars of 'Lady Stephanie' and cultivars with *Verticordia* as another parent by 1.3- and 1.2-fold, respectively. The vase solution of HQS and STS significantly ( $p = 0.05$ ) prolonged the vase life of 'Lady Stephanie' and cultivars with *Verticordia* as another parent by 1.4- and 1.3-fold, respectively, but did not improve the vase life of 'WX97' compared to the DI controls. The vase solution of HQS also significantly ( $p = 0.05$ ) prolonged the vase life of 'Lady Stephanie' by 1.2-fold, but did not prolong the vase life of 'WX97' or cultivars with *Verticordia* as another parent. The vase life of 'WX102' and 'WX17' was doubled in vase solutions of sucrose and HQS with or without STS, but had a 1.5-fold increase in vase solutions of HQS or HQS and STS compared to the DI controls. Similarly, the vase life of 'Purple Pride' doubled in vase solutions of sucrose and HQS or sucrose, HQS and STS, but vase life in HQS or HQS and STS vase solutions was not significantly ( $p = 0.05$ ) different to those in the DI controls. The vase life of 'Jasper' and 'WX73' in the vase solution containing sucrose, HQS and STS was not significantly ( $p = 0.05$ ) different from those in vase solution of HQS and STS, but was longer with a 1.3- and 1.4-fold increase than those in the vase solution of sucrose and HQS (Fig. 2).

### **Effect of vase solutions – leaf vase life**

Leaf vase life for all cultivars in the vase solution of sucrose, HQS and STS did not significantly ( $p = 0.05$ ) differ to leaf vase life in vase solution of HQS and STS or the DI controls, but was significantly ( $p = 0.05$ ) longer with a 1.2- or 1.4-fold increase than the leaf vase life of HQS or sucrose and HQS vase solutions (Fig. 3). The leaf vase life of most cultivars except for 'Lady Stephanie', 'WX73' and 'WX17' decreased in vase solution of HQS compared to the DI controls. The leaf vase life of *C. uncinatum* cultivars was significantly ( $p = 0.05$ ) improved by 1.6-fold in vase solutions of sucrose, HQS and STS, and by 1.2-fold in vase solution of sucrose and HQS, but did not increase in vase solutions of HQS or HQS and STS compared to the DI controls. The vase life of cultivars with *C. megalopetalum* as another parent, except for 'WX102', in vase solution of HQS and STS was significantly ( $p = 0.05$ ) shorter than vase life in the DI water, which was significantly ( $p = 0.05$ ) greater with a 1.3-fold increase than that of vase solutions of HQS or sucrose, HQS and STS and with a 2.0-fold increase over vase life in a vase solution of sucrose and HQS. The vase life of cultivar Southern Stars in DI water was similar to that of other vase solutions while the vase life of 'WX73' in DI water was similar to that of sucrose and HQS but significantly ( $p = 0.05$ ) shorter than the vase life in vase solutions of HQS or HQS and STS or sucrose and HQS and STS. On the other hand, the vase life of 'Jasper' in DI water was significantly ( $p = 0.05$ ) longer than that of other solutions. The vase life of 'WX97' was significantly ( $p = 0.05$ ) longer, with a 1.2-fold increase in vase solutions of sucrose, HQS and STS, but it decreased by half in the remaining vase solutions compared to the DI controls. Alternatively, the vase life of 'Lady Stephanie' was significantly ( $p = 0.05$ ) longer with a 1.4-fold increase in vase solutions of sucrose, HQS and STS and 1.3-fold in vase solutions of sucrose and HQS or HQS and STS compared to the DI control, which was similar to the vase solution of HQS in increasing vase life (Fig. 3). The vase life of 'Monica's Blush' and 'Purple Pride' was significantly ( $p = 0.05$ ) longer, with a 1.6-fold increase, than vase life in the DI controls or vase solutions of HQS or HQS and STS. The vase life of 'WX17' in sucrose and HQS and STS was significantly ( $p = 0.05$ ) longer, with a 2.5-fold increase over vase life in the DI controls and with a 1.8-fold increase over vase life in the vase solution of sucrose and HQS. Compared to the DI control, the vase solution of HQS and STS

**Table 2.** Percentage of stem fresh weight at the end of flower vase life in vase solutions

Cultivars	Control	HQS	HQS and STS	Sucrose and HQS	Sucrose, HQS and STS	Average fresh weight
Purple Pride	67.4 ± 1.5	42.7 ± 3.0	63.5 ± 6.0	72.8 ± 9.1	74.0 ± 3.9	64.1 ± 4.7
Mullering Brook	86.9 ± 5.4	57.7 ± 4.2	61.1 ± 8.4	66.4 ± 4.2	78.3 ± 2.6	70.1 ± 5.0
Monica's Blush	77.7 ± 2.7	70.5 ± 2.8	68.4 ± 2.8	64.7 ± 3.3	84.9 ± 3.3	73.2 ± 3.0
WX17	73.3 ± 5.0	76.2 ± 1.7	78.6 ± 5.3	74.6 ± 6.4	95.4 ± 1.9	79.6 ± 4.1
WX87	68.4 ± 5.4	69.8 ± 8.5	81.7 ± 2.1	65.1 ± 13.2	91.0 ± 7.0	75.2 ± 7.2
Matilda	79.5 ± 5.6	63.8 ± 4.3	78.1 ± 2.9	48.8 ± 4.8	70.7 ± 3.7	68.2 ± 4.3
Bridal Pearl	87.0 ± 3.1	74.5 ± 2.5	83.3 ± 0.6	89.3 ± 1.4	92.7 ± 5.5	85.4 ± 2.6
Denmark Pearl	79.3 ± 4.8	51.5 ± 7.7	90.4 ± 2.2	56.4 ± 11.8	66.1 ± 4.4	68.7 ± 6.2
Laura Mae Pearl	82.9 ± 3.6	86.3 ± 2.0	92.2 ± 3.2	105.1 ± 1.9	98.4 ± 9.6	93.0 ± 4.1
Chrystal Pearl	69.4 ± 2.8	65.7 ± 8.8	74.3 ± 4.4	70.2 ± 9.3	86.4 ± 4.7	73.2 ± 6.0
WX102	83.4 ± 4.1	72.3 ± 5.1	87.0 ± 1.9	101.3 ± 4.4	100.5 ± 4.2	88.9 ± 3.9
Jasper	87.5 ± 3.0	64.2 ± 7.9	77.7 ± 2.2	64.7 ± 7.1	79.9 ± 3.9	74.8 ± 4.8
Southern Stars	77.8 ± 3.5	64.4 ± 8.8	73.1 ± 6.9	83.9 ± 2.0	96.4 ± 6.8	79.1 ± 5.6
WX73	75.1 ± 1.6	80.3 ± 4.8	86.5 ± 1.2	64.6 ± 4.9	79.5 ± 3.4	77.2 ± 3.2
WX97	69.1 ± 8.2	59.4 ± 5.0	86.7 ± 3.9	60.9 ± 11.0	90.0 ± 3.0	73.2 ± 6.2
Lady Stephanie	79.4 ± 3.8	58.7 ± 6.7	64.8 ± 6.2	53.6 ± 3.8	60.2 ± 5.9	63.3 ± 5.3
Average fresh weight	77.8 ± 4.0	66.1 ± 5.0	78.0 ± 3.8	71.4 ± 6.2	84.0 ± 6.0	75.5 ± 5.0

LSD for cultivars = 6.8 days, for vase solution = 3.8 days and for cultivars × vase solution = 15.3 days by analysis of variation at  $p = 0.05$ ; ± – standard errors of the mean

significantly ( $p = 0.05$ ) increased the vase life of 'WX87' by 1.7-fold compared to 1.3-fold in vase solutions of HQS or sucrose, HQS and STS and 1.0-fold over the vase solution of sucrose and HQS.

#### **Relationship between the vase life of flowers and leaves**

Leaf vase life for all cultivars in the DI water, except for three out of four cultivars of *C. uncinatum* and two out of three *Verticordia* hybrids, exceeded flower vase life by an average of 5.0 days. In addition, the leaf vase life of *C. megalopetalum* × *C. uncinatum* hybrids exceeded the vase life of the flowers by an average of 44% or 8.0 days. The leaf vase life of three out of four *C. uncinatum* cultivars was 13% less than their flower vase life, with only 'Purple Pride' having a leaf vase life that was 2.0 days longer than its flower vase life (Figs 2 and 3). The leaf vase life of cultivars with *C. sp. Gingin* as a parent in DI water was longer, with a 1.8-fold increase over their flower vase life, followed by cultivars with *C. megalopetalum* as a parent, with 1.5-fold. Leaf vase life of cultivars with *Verticordia* as a parent in DI water was greater, with a 1.5-fold increase for 'Jasper' and 'WX73' and 13% less for 'Southern Stars' than the flower vase life and with a 1.2-fold increase for *C. floriferum* hybrid. The leaf vase life of the cultivars was similar to their flower vase life in vase solutions of HQS or HQS and STS,

but was significantly ( $p = 0.05$ ) – 54% and 17% – shorter in vase solutions of sucrose and HQS or sucrose, HQS and STS (Figs 2 and 3).

#### **The relationship between flower vase life, stem fresh weight and day for when stem fresh weight reached 75% of initial weight**

The percentage of fresh weight at the end of vase life was on average  $75.5 \pm 5\%$  over all of the cultivars and vase solutions. In vase solution of HQS there was a significant ( $p = 0.05$ ) decrease – 9% on average – of fresh weight at the end of vase life compared to that in DI water. However, for other vase solutions no difference occurred in the average fresh weight at the end of vase life for all cultivars compared to the DI water controls. On average for all cultivars, only those in the vase solution containing HQS had a significantly ( $p = 0.05$ ) lower fresh weight of 15% than those in DI water and other vase solutions. 'Southern Stars', 'Denmark Pearl', 'Matilda', 'Bridal Pearl', 'Lady Stephanie', 'Jasper', 'WX102', 'WX97', 'Mullering Brook' and 'Purple Pride' in vase solution of HQS reached the end of their vase life at 42.7%, which was significantly ( $p = 0.05$ ) lower than in DI water and other vase solutions, with an average of 68.4%, while 'WX102' in vase solutions of sucrose, HQS and STS reached its end of vase life at a significantly ( $p = 0.05$ ) higher percentage of fresh weight than in

the DI control, HQS or sucrose and HQS, as did 'Laura Mae Pearl' in the vase solution of sucrose and HQS. Across all of the vase solutions, cultivars of Crystal Pearl, Denmark Pearl, Matilda, Lady Stephanie, Mullering Brook and Purple Pride reached the end of their vase life at an average of 67.9% fresh weight, which was significantly ( $p = 0.05$ ) lower than that of 'Southern Stars', 'Bridal Pearl', 'WX73' and 'WX17', with an average of 80.3%, and was also significantly ( $p = 0.05$ ) lower than that of 'Laura Mae Pearl' and 'WX102', with an average fresh weight of 91.0% (Tab. 2).

## DISCUSSION

### *Effect of genotype*

Variation in vase life among cultivars was not always dependent on the particular genetic background of the cultivar, although cultivars solely with *C. uncinatum* in their genotype tended to have a shorter vase life than cultivars with *C. megalopetalum* or a different species such as *V. plumosa*. This appears to be dependent on the ability of the genotypes to maintain water balance. Symptoms associated with the end of vase life in *Anthurium* cultivars are typical of water stress when the balance between water loss and water uptake exceed 1.5 (Mujaffar and Sankat 2003). Similarly, in cut waxflowers the ability to maintain a positive water balance in cut stems determined vase life as found in *Anthurium andraeanum* Hort., where flowers with a longer vase life had a greater ability to maintain a positive water balance, which appears to be an inherited trait (Elibox and Umaharan 2010). The short vase life of *C. uncinatum* cultivars is consistent to findings reported by Joyce and Jones (1992) and Seaton et al. (2010) and was attributed to a greater water loss in leaves than in flowers, decreasing water potential in leaves (Joyce and Jones 1992). The longer vase life of leaves compared to flowers of *C. megalopetalum* and *C. sp. Gingin* is similar to the results obtained for *Verticordia* flowers (Seaton 2006a) and may indicate that leaves dry out more slowly than flowers and do not compete with flowers for water reducing flower vase life. Observations (data not included) showed that 'Lady Stephanie' and 'WX97' had shorter leaves than the *C. uncinatum* cultivars, but longer than *C. megalopetalum* hybrids, possibly prompting greater water loss. Accordingly, 'Lady Stephanie' and 'WX97' had a longer flower vase life than *C. uncinatum* cultivars but shorter flower vase life than cultivars with *C. megalopetalum* as

a parent. The variation in the vase life of waxflower genotypes was consistent with the findings on *Verticordia* (Seaton 2006a), Asiatic hybrid *Lilium* (van der Meulen-Muisers et al. 1999), *Dianthus caryophyllus* (Downs 1988, Olley 1996) and *Antirrhinum majus* (Weber et al. 2005). In addition, the flower vase life of 'Southern Stars' (long vase life) at 2.2 times the vase life of 'WX73' (short vase life) was consistent with differences in the parents of these cultivars, where *V. plumosa* flowers and leaves had two to three times the length of vase life than *V. grandis* (Seaton 2006a).

### *Effect of vase solutions*

The ability of sucrose to improve water balance (Halevy and Mayak 1974, Kuiper et al. 1995) may have been a critical factor in improving the vase life of the waxflower cultivars used in this study, where flowers with a longer vase life dehydrated slower with sugar present in the vase solution. The different responses of waxflower cultivars to sucrose may indicate a different sensitivity of the cultivars to sucrose, as lower concentrations prolonged the vase life of gladiolus florets by increasing water uptake, whereas higher concentrations seemed to impede water uptake (Bravdo et al. 1974). As sucrose was more effective when HQS was added (Ichimura et al. 1999), suggesting that sucrose may encourage microbial blockage of stems, limiting water uptake. A significant increase in the vase life of *C. uncinatum* cultivars when treated with sucrose and HQS was similar to the result for 'Purple Pride' and 'Alba' (Joyce and Jones 1992). HQS acts an antimicrobial agent (Ketsa et al. 1995), resulting in an increased water uptake of cut flowers (Reddy et al. 1996). HQS at 200 mg L<sup>-1</sup> in vase water prolonged the flower vase life of cut snapdragon (Asrar 2012) and rose (Ichimura et al. 1999). However, in this study HQS was ineffective in extending the vase life of waxflowers, which is supported by the results of van Doorn et al. (1990) and Liao et al. (2000), and also shortened leaf vase life, which could be caused by HQS being toxic. The reduction in leaf vase life of some cultivars treated with sucrose and HQS may indicate that concentrations of HQS were toxic to some cultivars, especially their leaves. Sucrose at 58.48 mmol may also have been toxic to some cultivars, as Joyce (1993) found that high sucrose concentrations (i.e. 146.2 mmol) may cause leaf tip injury through osmotic stress of sucrose accumulation. Also in this study, sucrose at 58.48 mmol caused leaf tip injury in 'Purple Pride' and desiccated the leaves of the

*C. megapetalum* hybrids. This indicates the leaves of 'Purple Pride' experienced more turgor loss than leaves of the *C. megapetalum* hybrids. Variation in the leaf vase life of waxflowers caused by genotypic variance was consistent with the finding on *Protea neriifolia* where pulsing with 584.8 mmol sucrose (24 h, 25°C) significantly reduced leaf blackening in *Protea neriifolia* (McConchie and Lang 1993), but not for *Protea* 'Sylvia' (Stephens et al. 2011). STS was more effective in prolonging the vase life of leaves than the flowers of waxflowers, with leaf vase life significantly increased with the presence of STS in the HQS vase solution, suggesting that STS can reduce the deleterious effect of HQS. STS prevents ethylene induced abscission (Serek and Sisler 2001) and was very effective in preventing flower abscission of *C. megalopetalum* hybrids (Seaton 2005) and *C. uncinatum* cultivars (Joyce 1993), but was ineffective in increasing the vase life of cut *C. uncinatum* (Joyce 1988). STS combined with sucrose and HQS was more effective than sucrose and HQS in terms of increasing the vase life of cut waxflowers, which is supported by a study on cut rose (Liao et al. 2000). This may be due to the role of STS as an ethylene blocker (Joyce 1988) delaying the senescence of ethylene-sensitive flowers (Veen 1983, Knee 1995) and inhibiting the microbial population, which causes vascular occlusion of the stems (Asrar 2012).

## CONCLUSIONS

1. The influence of genotype caused a variation in the vase life of waxflowers, with the shortest vase life found for the cultivars of *C. uncinatum* and the longest vase life found for the cultivars that had *C. megalopetalum* or *Verticordia* as a parent.
2. The vase life of waxflower cultivars responded differently to vase solutions.
3. Vase solutions containing HQS, sugar and STS were effective in improving water balance and vase life. However, vase solutions with only HQS or HQS coupled with STS were ineffective in prolonging vase life.
4. The vase life of waxflower cultivars ended when stem fresh weight reached 75%.

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## AUTHOR CONTRIBUTION

All authors contributed extensively to the work presented in this paper. C.D.D. conducted the research work, collected and analysed data and wrote the research work; K.S. designed the experiments, provided the samples, gave suggestions and corrected the manuscript; Z.S. gave suggestions and corrected the manuscript.

## CONFLICT OF INTEREST

The authors declare no conflicts of interests.

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