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Effects of postharvest pretreatments and preservative solutions on vase life longevity and flower quality of sweet pea (*Lathyrus odoratus* L.)

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Abstract

The effects of postharvest pretreatments on vase life, keeping quality and carbohydrate concentrations in cut sweet pea (*Lathyrus odoratus* L.) flowers were investigated. Compared to the control, all treatments promoted floret quality and extended longevity. The cut flowers held in the solution containing sucrose + 8-hydroxyquinoline (Suc+HQS) was more effective in promoting absorption rate, achieved greater maximum fresh mass, had better water balance for a longer period, extended the vase life (up to 17 d), and delayed degradation of chlorophylls. The same treatment also enhanced the concentration of soluble carbohydrates in the petals and stems and leaf chlorophyll (Chl) content, whereas it was lowest in silver thiosulphate (STS) treatment. However, concentrations of anthocyanin in the petals were higher for treatment with sucrose or STS plus sucrose than in control or STS alone treatments. Our results suggest that pulse treatment with HQS plus sucrose for 12 h is the most effective for improving pigmentation and use as a commercial cut flower preservative solution to delay flower senescence, enhance quality, and prolong the vase life of sweet pea. The results also showed that soluble carbohydrate concentration in petals and stems is an important factor in determining the vase life of sweet pea flowers.

Additional key words: cut flower; sweet pea; preservative solution; vase life; water relations.

Introduction

Sweet peas are one of the most popular flowers worldwide. They are available in a wide range of colours and they have an exceptional fragrance. However, because of their short vase life and the difficulties associated with handling and transport, the commercial production of these flowers is very small. Postharvest problems include the delicacy of the opened florets and early floret senescence. Sweet pea flowers are highly sensitive to ethylene, and the cut flowers have a very short vase life (Woltering and van Doorn 1988, Ohkawa *et al*. 1991).

The criterion for evaluating the effect of floral preservatives on cut flowers is the maintenance of quality with maximum longevity (vase life) when the flowers are used by the consumer. One of the greatest problems in postharvest flower physiology is the blockage of the vascular system due to air or bacterial growth. This results in reduced water uptake, and combined with the blockages in the xylem vessels, results in water stress (Van Meetern *et al*. 2001). This has been observed as early wilting flowers (Henriette and Clerkx 2001), which resulted from the loss of cell turgor caused by an imbalance between transpiration and water uptake over a long period. All holding solutions must contain two components; sugar and germicides. The germicide 8-hydroxyquinoline sulfate (8-HQS) is a very important preservative. It acts as an antimicrobial agent (Ketsa *et al*. 1995) and increases water uptake by reducing ‘physiological’ stem blockage in sterile tissues (Reddy *et al*. 1996). However, this treatment is more effective when combined with the addition of sucrose (Ichimura *et al*. 1999). Sucrose is the most commonly used sugar for prolonging the vase life of cut flowers. The exogenous supply of sucrose provides the cut flowers with much needed substrates for respiration. In addition, it enables cut flowers harvested at the bud stage to open, which otherwise could not occur naturally (Pun and Ichimura

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Abbreviations: 8-HQS – 8–hydroxyquinoline sulfate; Chl(s) – chlorophyll(s); DI – deionized water; DM – dry mass; FM – fresh mass; HPLC – high performance liquid chromatography; IFM – initial fresh mass; STS – silver thiosulfate; Suc + HQS – sucrose plus hydroxyquinoline sulfate solution; Suc + STS – sucrose plus silver thiosulfate solution.
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2003). The use of 1.38 mM 8-HQS + 58.43 mM sucrose provided sufficient osmotic pressure for stems to take up a significant amount of water during the postharvest period. Therefore, this preservative solution may have potential as a commercial preservative solution for cut sweet pea flowers.

As well as 8-HQS, silver thiosulfate (STS) treatments could improve the keeping quality and vase life of sweet pea cut flowers. STS acts as an ethylene antagonist, reducing ethylene production and respiration (Veen 1979) and extending floral longevity (Reid *et al*. 1980). Sexton *et al*. (1995) reported that a pulse treatment of sucrose and/or STS effectively prolonged the vase life of cut sweet pea flowers. The combined effect of sugars and antimicrobial agents increased vase life by up to 0.2 mM, and improved spike quality of two gladiolus cultivars (Al-Humaid 2004). To date, there have been few studies on the effects of pulse treatments with sucrose and/or STS on improving the vase life of cut sweet pea flowers.

Therefore, the main objective of the present study was to investigate the roles of various possible preservative solutions and further to probe their role in processes such as Chl and carbohydrate metabolism which are connected to cut flower longevity and quality of sweet pea cut flowers, a major concern for growers as well as exporters.

Materials and methods

Plants: Sweet pea plants (*Lathyrus odoratus* L.) cv. Diana were grown under standard greenhouse conditions (22°C days, 15°C nights) of Agricultural Experiment Station (Dirab), 50 km south of Riyadh City, Saudi Arabia, that has the following characters: 24°6'N, 46°5'E, 650 m a. s. l.; 10°C in winter and 37°C in summer, the mean relative humidity 82%, and the average rainfall 300–380 mm. There are no grade standards for sweet pea flowers, but quality flowers have long, straight stems, and at least five buds on each spike.

Flower harvesting and measurement: Sweet pea flower spikes were harvested from the plant on October 21, 2009 and cut when the last bud on the stem was about half open. At this stage, the flowers are in the "bud stage", in which the petals on the first bud are coloured and near full size, but have not yet opened. Flowers are harvested by holding the stem between the thumb and forefinger near the base (supporting the vine with two fingers behind and one in front) and then pulling the flower backwards and upwards from the axil of the leaf. The flowers were cut in the early morning, wrapped in Kraft paper in groups and translocated vertically under dry conditions to the laboratory within two hours. The cut spikes were brought to the laboratory of the Plant Production Department, College of Food and Agricultural Sciences, King Saud University. All experiments were performed in a controlled environment at 22 ± 2°C and 60 ± 10% relative humidity with 12-h lighting by cool white fluorescent lamps (65 W, 240 V; *Phillips Lighting*, Bloomfield, NJ, USA) providing a total light intensity of 10 µmol m^{-2} s^{-1}. Immediately on receipt, the flower stem was recut 1 cm from the base under water to avoid air embolisms and the height of all flower stems set on 29 cm.

Chemical treatment: Treatments were set following randomized completely blocked design. Each treatment consisted of 10 replicates (bottles), and each bottle contained one cut flower stem (one spike). To examine the effects of the vase solution components on the keeping quality of sweet pea cut flowers, six different preservative solutions (treatments) were applied, as follows: T_1: 58.43 mM sucrose; T_2: 1.38 mM 8-HQS; T_3: pulsing of spikes with 1.38 mM 8-HQS + 58.43 mM sucrose for 12 h; T_4: pulsing of spikes with 0.2 mM silver thiosulfate (STS) for 1 h; T_5: pulsing of spikes with 0.2 mM STS for 1 h followed by 58.43 mM sucrose solution; T_0: or deionized water (DI). The STS was prepared as described by Gorin *et al* (1985). Briefly, 0.079 g $AgNO_3$ was dissolved in 500 ml of deionized water, and 0.462 g $Na_2S_2O_3 \cdot 5\ H_2O$ was dissolved in another 500 ml deionized water. Then, the two solutions were combined with stirring. The concentration of silver in the resulting solution was 0.463 mM. Different concentrations of preservative solutions were prepared and deionized water of pH 5.6 was used to make the dilutions. The same deionized water was used as control. After pulsing, the assigned samples of flower stems were immediately transferred into the containers filled with simple deionized water. However, flower cuttings treated with sucrose concentration were not transferred into simple deionized water; rather they remained in their respective solutions. Equal volume of solution was assigned to all treatments.

Vase life: Longevity of cut flowers (spikes) was determined as the time from harvest to when the last floret wilted. Florets were considered to have terminated their life when petals lost their turgor, discolouration and inrolling of the petal distal edge and the spike has lost its decorative value.

Water relations: The solution uptake by the cut spikes was recorded at regular interval. The average daily vase solution uptake rate (VSU) was calculated using the formula: VSU [g g^{-1} initial fresh mass (IFM)] = [S(t–1) – S(t)]/IFM of the spike, where S(t) is the mass of vase solution [g] at t = day 1, 2, 3, *etc*., and S(t–1) is the mass of vase solution [g] on the previous day (Damunupola 2009). The components of water balance are water uptake and water loss, and the capacity of the flower tissue to retain its water (Halevy and Mayak 1981).

Maximum increase of fresh mass (FM): The original

FM was measured immediately after cutting flowers and before immersing in treatment solutions. The cut flower spikes were weighed every day during the experiment. The FM of each cut spike is expressed relative to its initial mass to give the percentage of mass loss for each cut flower (He *et al*. 2006). For measuring of DM to FM ratio, FM was measured every 2 days and after the end of the vase life, all of the cut flowers were dried in an oven at 60°C for 72 h and then weighed to get DM.

Chl determination: Chls were extracted from sweet pea leaf samples (0.59 g) collected on day 0 (at the beginning of experiment), day 3, and on the final day of the vase life of the flower spikes in the control (day 7). The samples were collected separately from each replicate and the average of the three replicates was calculated. Chls were extracted in acetone, and extractions were repeated until the tissue was completely colorless. The absorbance of the extracts was determined using a spectrophotometer (type *GBC, UV/VIS 916*, Australia). Leaf Chl concentration was determined from measurements of absorbance of the extracts (Holden 1965, Douglas 1983). The Chl content was determined according to the equations reported by Moran and Porath (1980) and calculated from a previously plotted standard curve. The Chl content was calculated as mg g^{-1}(DM). The equations for determining concentrations of Chl *a* and Chl *b* were as follows:

$$\text{Chl } a = 11.24\ A_{661.6} - 2.04\ A_{644.8}$$
$$\text{Chl } b = 20.13\ A_{644.8} - 4.19\ A_{661.6}$$

where A is the absorbance value at each specified wavelength.

Sugar content was determined in stems and petals of flowers in the various treatments and the control. Samples were taken on day 1, 3, and 5 of the experiment. The stems and petals were extracted in 2 or 5 mL of 80% ethanol depending on the mass of the sample, by shaking for 3 h. After cooling, 20 µl of 50 g l^{-1} glycerol was added to the solution as an internal standard. The sample was homogenized and centrifuged at 3,000 × *g* for 10 min. The three supernatants were combined and concentrated *in vacuo* below 40°C. The residue was redissolved in 1 ml of distilled water. This solution was analyzed using a *Jasco* HPLC system (Tokyo, Japan) equipped with a refractive index detector on a *Shodex SUGAR SP0810 column* (*Showa Denko*, Tokyo). The column was kept at 80°C and eluted with water at a rate of 0.8 ml min^{-1}. The concentration of each carbohydrate in the sample was calculated as previously described (Cho *et al.* 2001). Measurements were repeated 3 times.

Anthocyanin was extracted from 5 g of fresh sweet pea petals with 50 ml of methanol, 1% (v/v) HCl (Harbone 1984) for 1 h. The extract was then filtered with *Whatmann 110* filter paper for use in subsequent experiments. Total anthocyanin concentration was determined by measuring the absorbance of the extract at 530 nm using a spectrophotometer (*Prim, SECOMAM*, France). All measurements were done in three replicates and each experiment was repeated 3 times.

Statistical analysis: The data were statistically analyzed using a randomized block design with three replications with 10 flowers per treatment. Means were separated by *Duncan*'s multiple range tests by the least significant difference (LSD, $P \leq 0.05$) method using *CoStat* (*Version 6.303, CoHort*, USA, 1998–2004). All of the measurements were performed 3 times for each treatment, and the means and calculated standard errors (SE) are reported.

Results

Vase life: In this study, the vase life of sweet pea was significantly affected by their treatments compared with the control (Table 1). Pulse treatment with 8-HQS alone significantly extended the vase life of florets already opened on the day of harvest but did not extend the vase life of flower spike. Treatment with sucrose at 58.43 mM extended the vase life of the floret and spike more than treatment with 8-HQS and other treatments. The vase life of flowers in the control was 7 d, compared with 11.35 d in the 58.43 mM sucrose treatment and 14.33 d in the 1.38 mM 8-HQS treatment. Our experiment is in agreement with Ichimura and Hiraya (1999) who mentioned that treatment with sucrose extends the vase life of sweet pea florets harvested at a bud stage. Keeping the flowers in vase solutions containing sucrose has been shown to extend their vase life (Han 2003, Yamane *et al*. 2005). Our results showed that addition of sucrose positively correlated with vase life of the sweet pea cut flower (Table 1).

Water relations: As shown in Table 1, results regarding the water uptake by the sweet pea flowers showed that maximum water uptake was in sweet pea flowers that were treated by T_3 treatment and this treatment differed significantly with each other (8-HQS only, STS only, STS followed by sucrose). The maximum quantity of holding solution was absorbed in T_3 treatment (7.08 ml), compared with 2.95 ml in the control (T_0). The determination of water balance in the present study provides a clear picture of water relations of the inflorescence throughout its vase life of cut sweet pea. Among the different treatments, the overall water balance showed the same trends. However, as shown in Fig. 1, the flowers that were treated with T_3 showed better water balance than those in other treatments.

Maximum increase of FM: The FM of sweet pea cut flowers in sucrose alone or 8-HQS plus sucrose treatment were significantly greater than in those in control and

Table 1. Effect of the different preservative solutions on vase life, water uptake and percentage of maximum increase in fresh mass (FM) of sweet pea cut flowers. Values in each column followed by *the same letter(s)* are not significantly different at $P \leq 0.05$ (*Duncan*'s multiple range test). Each value represents the mean of three replicates ± SE.

Treatments	Vase life [d]	Water uptake [ml flower^{-1} day^{-1}]	Maximum increase in FM [%]
Deionized water (control, T_0)	7.00 ±0.71^{d}*	2.95 ± 0.05^{e}	29.28 ± 0.15^{f}
58.43 mM sucrose (T_1)	11.33 ± 0.41^{c}	3.28± 0.12^{d}	31.75 ±0.12^{e}
1.38 mM 8-HQS (T_2)	14.33 ± 0.41^{b}	5.65 ± 0.66^{b}	39.39 ±0.32^{c}
Suc + HQS (T_3)	17.00 ± 0.71^{a}	7.06 ± 0.16^{a}	55.25 ± 0.37^{a}
0.2 mM STS (T_4)	14.00 ± 0.41^{b}	3.58 ± 0.08^{c}	34.92 ± 0.32^{d}
Suc + STS (T_5)	15.00 ± 0.71^{b}	5.73 ± 0.06^{b}	43.53± 0.34^{b}
LSD (0.05)	1.39	0.24	0.72

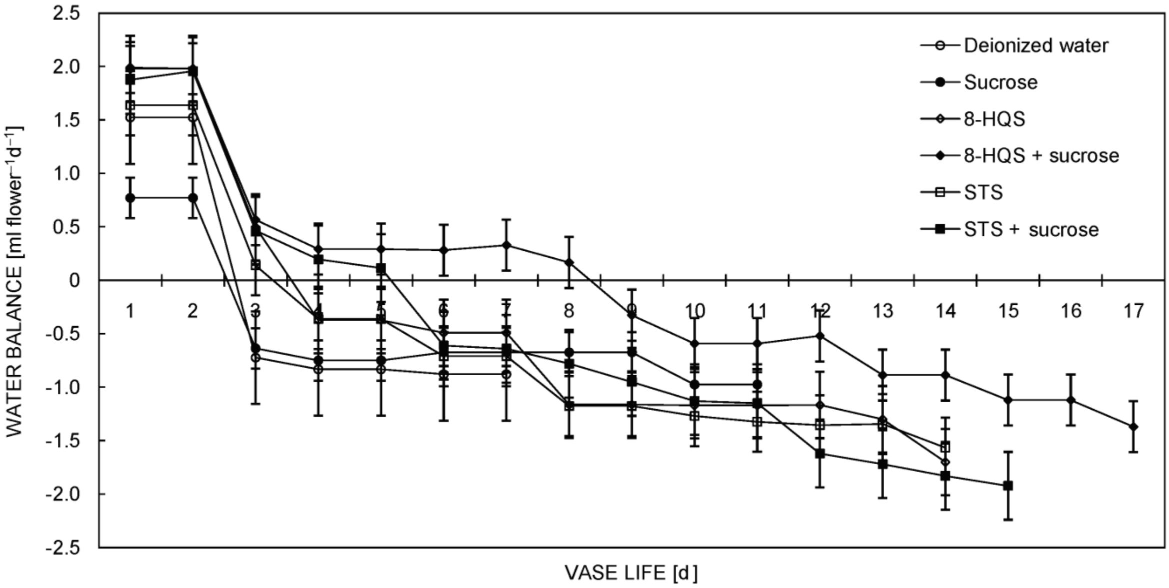

Fig 1. Water balance of sweet pea cut flowers as affected by different preservative solutions during vase life.

8-HQS treatments (Table 1), indicating that pulse treatment with solution containing sucrose promotes floret development. The maximum increase in FM during the vase life period was 55.25% in T_3 (compared with 29.28% in T_0). A similar trend was reported by Kim and Lee (2002) and Elgimabi and Ahmed (2009), who showed that the hydraulic conductance of cut roses stem segments after harvest was maintained almost at its initial level in the HQS + sucrose and HQS treatments, but that of cut stem segments in the control decreased rapidly.

Leaf Chl content: T_3 and T_5 treatments significantly increased the total Chl content to a larger extent when compared to control (P=0.05). The maximum total Chl content was noted in T_3 treatment compared to control. The minimum total Chl content was noted in T_4 compared to control. As shown in Fig. 2, the T_3 treatment was the most effective treatment for delaying Chl degradation as evidenced by the high leaf Chl content retention. In all treatments and the control, the concentration of Chl *a* was higher than Chl *b* at all time points during the vase life of the sweet pea flowers. The differences in Chl content became more and more apparent as the duration of postharvest increased. At the end of the vase life of control flowers (day 7), the differences clearly appeared and control flowers lost Chl rapidly. 8-HQS treatment was more effective than STS in this respect, but there were no significant differences between them. Ewa *et al.* (2004) showed that a standard preservative solution containing 2% sucrose and 200 mg dm^{-3} citrate or sulphate of hydroxyquinoline (8-HQC or 8-HQS) increased Chl content in leaves of *Zantedeschia aethiopica* and *Z. elliottiana*. A present result showed that addition of 8-HQS and sucrose was found to be positively correlated with total Chl content of the sweet pea cut flower (Fig. 2).

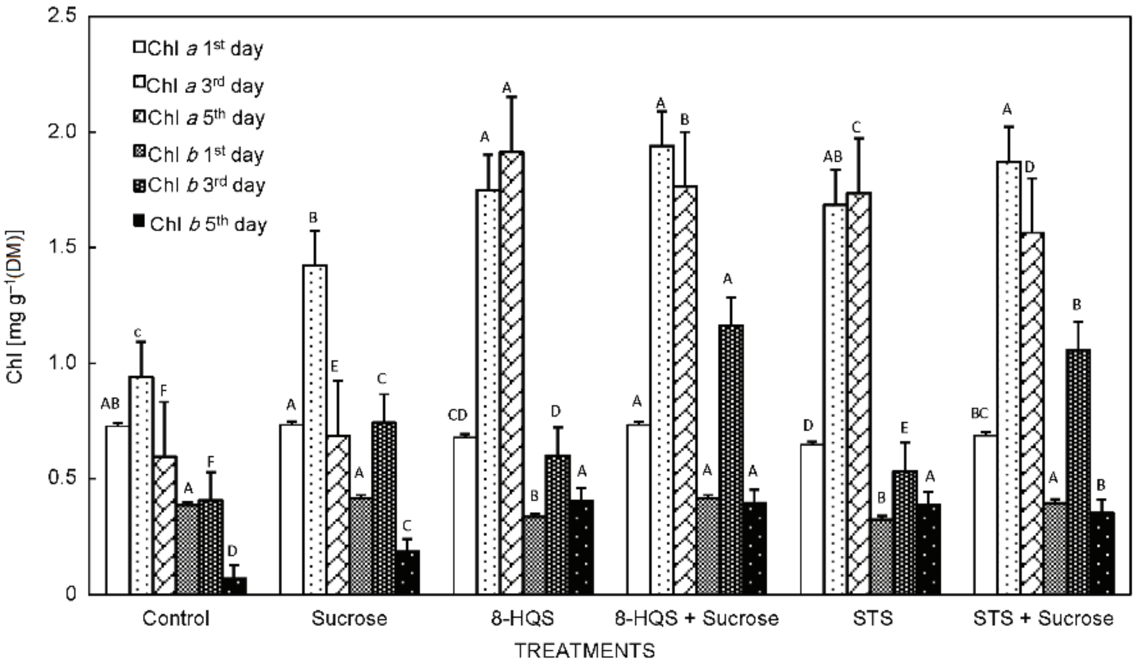

Fig 2. Effect of different preservative solutions on chlorophyll (Chl) *a* and *b* contents of leaves of sweet pea cut flowers during vase life. Each value represents the mean of three replicates ± SE. DM – dry mass.

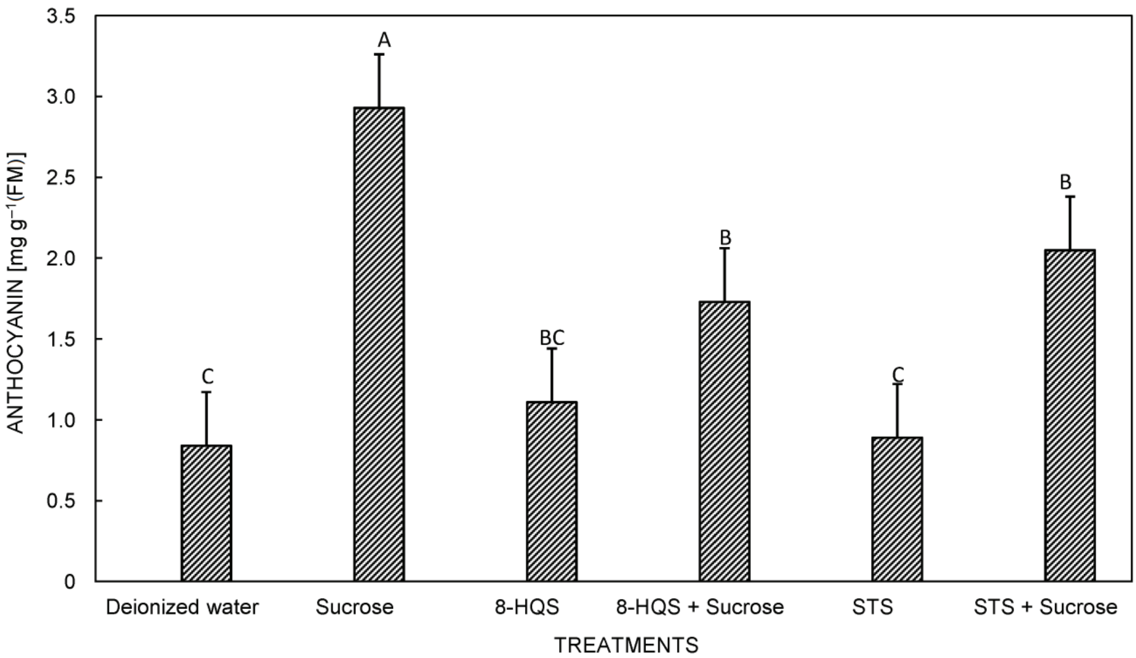

Fig 3. Effect of the different preservative solutions on anthocyanin concentrations of petals of sweet pea cut flowers. Values in each bar followed by *the same letter* are not significantly different at $P \leq 0.05$ (*Duncan*'s multiple range test). Values shown are means ± SE of three replicates. FM – fresh mass.

Sugar content: Fructose, glucose, and sucrose were the main soluble carbohydrates in both petals and stems of sweet pea cut flowers, and generally, their content was higher in petals than in stems (Tables 2, 3). The carbohydrate content, whether in petals or stems, of the control increased from the beginning of the experiment till day 3 and sharply decreased till day 7, which was the last day in vase life of control flowers. The main sugar in petals was fructose, followed by glucose. Concentrations of glucose and fructose were highest in petals in T_3 treatment followed by the T_5 treatment, and lowest in the T_2,

Table 2. Effect of the different preservative solutions on carbohydrate content [mg g^{-1}(dry mass)] for petals of sweet pea cut flowers. Values in each column followed by *the same letter(s)* are not significantly different at $P \leq 0.05$ (*Duncan*'s multiple range test). Each value represents the mean of three replicates ± SE.

Treatments	Time of determination of carbohydrate content [d]								
	1			3			5		
	Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose
Deionized water (control, T_0))	$0.91 \pm 0.01^{f*}$	0.30 ± 0.01^{d}	0.08 ± 0.01^{e}	0.13 ± 0.01^{d}	0.03 ± 0.01^{f}	0.02 ± 0.01^{b}	0.65 ± 0.01^{d}	0.14 ± 0.01^{d}	0.29 ± 0.02^{c}
58.43 mM sucrose (T_1)	1.35 ± 0.01^{e}	1.97 ± 0.01^{c}	0.43 ± 0.01^{d}	2.99 ± 0.01^{b}	1.95 ± 0.01^{e}	1.22 ± 0.08^{c}	0.37 ± 0.06^{e}	0.88 ± 0.07^{c}	0.11 ± 0.01^{e}
1.38 mM 8-HQS (T_2)	2.87 ± 0.01^{c}	1.97 ± 0.01^{c}	1.00 ± 0.01^{b}	2.06 ± 0.01^{c}	2.99 ± 0.08^{c}	0.08 ± 0.01^{d}	1.93 ± 0.01^{c}	1.24 ± 0.01^{b}	0.15 ± 0.01^{d}
Suc + HQS (T_3)	4.18 ± 0.06^{a}	3.55 ± 0.05^{a}	1.23 ± 0.01^{a}	5.97 ± 0.01^{a}	4.34 ± 0.05^{a}	1.99 ± 0.01^{a}	2.87 ± 0.08^{a}	1.63 ± 0.06^{a}	1.01 ± 0.01^{a}
0.2 mM STS (T_4)	2.43 ± 0.01^{d}	1.82 ± 0.12^{c}	0.89 ± 0.01^{c}	2.03 ± 0.01^{c}	2.56 ± 0.06^{d}	0.05 ± 0.01^{d}	1.85 ± 0.08^{c}	1.12 ± 0.06^{b}	0.08 ± 0.01^{e}
Suc + STS (T_5)	3.65 ± 0.09^{b}	2.85 ± 0.06^{b}	1.07 ± 0.01^{b}	2.99 ± 0.1^{b}	3.74 ± 0.04^{b}	1.53 ± 0.06^{b}	2.41 ± 0.18^{b}	1.15 ± 0.09^{b}	0.75 ± 0.04^{b}
LSD (0.05)	0.13	0.16	0.07	0.11	0.12	0.11	0.23	0.15	0.05

Table 3. Effect of the different preservative solutions on carbohydrate content [mg g^{-1}(dry mass)] for stems of sweet pea cut flowers. Values in each column followed by *the same letter(s)* are not significantly different at $P \leq 0.05$ (*Duncan*'s multiple range test). Each value represents the mean of three replicates ± SE.

Treatments	Time of determination of carbohydrate content [d]								
	1			3			5		
	Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose
Deionized water (control, T_0)	$0.91 \pm 0.01^{f*}$	0.30 ± 0.08^{e}	0.08 ± 0.08^{f}	0.70 ± 0.04^{d}	0.60 ± 0.11^{b}	0.11 ± 0.01^{d}	0.62 ± 0.09^{d}	0.43 ± 0.01^{c}	0.19 ± 0.01^{d}
58.43 mM sucrose (T_1)	1.17 ± 0.01^{e}	1.08 ± 0.01^{bc}	0.32 ± 0.01^{c}	2.32 ± 0.05^{c}	2.00 ± 1^{a}	1.23 ± 0.07^{c}	0.89 ± 0.01^{c}	0.47 ± 0.01^{c}	0.09 ± 0.03^{d}
1.38 mM 8-HQS (T_2)	1.95 ± 0.04^{c}	1.00 ± 0.04^{c}	0.16 ± 0.01^{d}	2.43 ± 0.08^{c}	2.00 ± 1^{a}	1.45 ± 0.11^{b}	0.87 ± 0.01^{c}	1.08 ± 0.01^{a}	0.69 ± 0.01^{b}
Suc + HQS (T_3)	2.21 ± 0.02^{a}	1.30 ± 0.02^{a}	1.07 ± 0.01^{a}	3.53 ± 0.05^{a}	2.11 ± 0.25^{a}	1.97 ± 0.01^{a}	1.51 ± 0.01^{a}	0.40 ± 0.04^{c}	0.84 ± 0.01^{a}
0.2 mM STS (T_4)	1.82 ± 0.01^{d}	0.89 ± 0.01^{d}	0.11 ± 0.01^{e}	2.31 ± 0.06^{c}	1.78 ± 0.13^{a}	1.32 ± 0.01^{c}	0.63 ± 0.01^{d}	1.01 ± 0.01^{b}	0.52 ± 0.09^{c}
Suc + STS (T_5)	2.03 ± 0.01^{b}	1.12 ± 0.01^{b}	1.02 ± 0.01^{b}	3.11 ± 0.06^{b}	1.92 ± 0.13^{a}	1.82 ± 0.1^{a}	1.24 ± 0.02^{b}	0.29 ± 0.01^{d}	0.65 ± 0.05^{b}
LSD (0.05)	0.05	0.09	0.03	0.13	1.08	0.17	0.08	0.05	0.11

treatment. Sucrose was also detected in petals. Sucrose concentration in 8-HQS and 8-HQS + sucrose treatments were lower than in other treatments (Tables 2, 3). In T_0, the concentrations of fructose, glucose, and sucrose in sweet pea petals were 0.65, 0.14, and 0.29 mg g^{-1} at the end of the experiment, respectively (Table 2). In comparison, their respective concentrations in the T_3 treatment were 1.93, 1.24 and 0.15 mg g^{-1}(DM) at the end of the experiment (Table 2). In the stems, the contents of the three sugars increased at the beginning and then decreased towards the end of the experiment, compared with the control (Table 3).

Anthocyanin concentration: The highest concentration of anthocyanin in sweet pea florets was in the sucrose-only treatment, followed by the STS and sucrose treatment. The STS-only treatment did not result in a significant increase in anthocyanin concentration compared with that of the control (Fig. 3). Since sucrose was applied to the spikes after a 1-h treatment of STS, flowers in the sucrose–only treatment may have taken up more sucrose. In spite of this, most studies on postharvest handling of cut flowers do not present data on the changes in pigmentation, and those that do use subjective colour grades for evaluation. Colour fading and discolouration is an important factor in determining display quality of cut flowers, and in many cases is the major reason for the termination of vase life (Biran *et al*. 1974).

Discussion

One of the greatest problems in postharvest flower physiology is the blockage of vascular system, due to air or bacterial growth, which reduces water uptake and this blocks xylem vessels leading to water stress (Hardenburg 1968). The results showed that the role of 8-HQS as antimicrobial agent and hence, it might act as a biocide, inhibiting growth of microbes that would otherwise have blocked vascular tissues (De Stigte 1981, Jones and Hill, 1993, Van Doorn *et al*. 1990). In the present study, addition of sucrose with 8-HQS resulted in a longer vase life than that in the 8-HQS-only treatment. Our results are consistent with those observed a pulse treatment of sucrose in combination with HQS extended the vase life of cut sweet pea flowers, suggesting that the sucrose might be required as an osmolyte for flower opening and substrate for cell wall synthesis and respiration (Halevy and Mayak 1979). Among all vase solution treatments, T_3 was found to be the most effective for improving vase life up to 17 dcompared with 7 d in T_0. However, no marked difference in vase life between STS and STS followed by sucrose was found, although the latter showed a slightly greater positive effect than the former (Table 1). The obtained results are in harmony with those found by Asrar (2012). However, Mor *et al.* (1984) also indicated that a pulse treatment with STS or STS with 4% sucrose was markedly effective in extending the vase life of cut sweet pea flowers. In addition, the superiority of HQS over STS may have been due to the relative immobility of STS in the stem (Veen and Van de Geijin 1978). On the other hand, continuous treatment with sucrose also delays ethylene production by snapdragon florets (Ichimura and Hisamatsu 1999), giving an additive effect of extending vase life of ethylene-sensitive flowers (Pun and Ichimura 2003). Thus, the observed extension of vase life by pulse treatment with sucrose might be due to the suppression of ethylene production.

The determination of water balance in the present study provides a clear picture of water relations of the inflorescence throughout its vase life of cut sweet pea. Previous studies (Nowak and Rudnicki 1990, Song *et al.* 1996) showed that the beneficial effects of HQS in preventing bacterial development in stock held in vase solutions containing sucrose. Thus, if bacterial growth can be eliminated, addition of sucrose (58.43 mM) results in better water balance of the cut sweet pea flowers. It is known that sucrose helps maintain water balance and also delays turgor loss as the flower senescence (Sven and Jose 2004). In addition, most probably after the supplied sugar reached the sweet pea flower head, an improvement in water balance was observed. The improvement of water balance was also associated with a reduced endogenous level of abscisic acid (Halevy 1976), which is a typical response to reduction of water stress. Similar results were also reported by Steinitz (1982) and Awad *et al.* (1986) in gerbera and zinnia, respectively. In case of sweet pea spikes, sucrose feeding maintained higher FM and DM of flowers as compared to controls. It is suggested that sucrose induces the closure of stomata, eventually reducing the loss of water, thereby reducing transpiration and maintaining FM (Marousky 1969, Chen *et al*. 2001).

The effective role of 8-HQS could be explained also by maintaining leaves turgidity, by keeping FM and Chl as well as carbohydrates losses by 8-HQS. Maintenance of DM of flowers could be also due to lower respiratory losses as sucrose has been found to suppress respiration in certain plant tissues by delaying climacteric rise in ethylene biosynthesis (Ichimura and Suto 1999, Zhang and Leung 2001, Ichimura *et al*. 2000). These results are in agreement with the findings of Knee (2000) and Bhattacharjee (1994). In this study, T_3 treatment also maintained the DM of the cut spikes which showed higher concentrations of sugars in sweet pea petals. A sustained level of petal sugars is known to restrict hydrolysis of cellular components (Yu 1999), the remobilization of nutrients (Koch 1996) and maintain flower DM, as observed in Asiatic lily (van der Meuler-Muisers *et al*. 2001).

In this study, sweet pea spikes increased their FM and enhanced availability of hexoses (glucose and fructose) in the petals due to increased solution uptake. The sugar content in both petals and stems varied through the evaluation period, decreasing after 3 d, possibly because of an increase in the respiration rate, and therefore, the sugars, initially stored in the floral buttons, were partially consumed (Tables 2, 3). At day 5, sugars began to decrease and as the senescence progressed the respiration rate increased exhausting the substrate. The increased reducing sugar in the floret and stem of sweet pea cut spikes may increase the osmotic potential of the stem and petals, thus improving their ability to absorb nutrients and maintain their turgidity, which may explain the increase of flower longevity in different treatment and observed in this study. Therefore, the effect of Suc+HQS on increasing quality cut spikes may be in its role in promotion of hydrolysis of starch and sucrose into fructose and glucose which delayed petal abscission and color fading. The same behaviour was observed in the stems, possibly because of the absence of sugar accumulation, stems are characterized mainly for being the site where the synthesis of carbohydrates takes place.

The results indicated that T_3 treatment reduced Chl degradation (Fig. 2) and preserved carbohydrate content (Tables 2, 3). This may be due to ethylene inhibitory effects of 8-HQS, as described in previous studies (Bartoli *et al*. 1997, WeiMing *et al*. 1997). Therefore, HQS could have delayed the degradation of Chl by possibly delaying the breakdown of protein used in the synthesis of Chl.

The treatment with sucrose alone increased anthocyanin concentrations of petals (Fig. 3). Tsukaya *et al.* (1991) and Moalem-Beno *et al.* (1997) reported with petunia that gene expression of chalcone synthase, a key enzyme of anthocyanin biosynthesis, is induced by sucrose. Thus, stimulation of anthocyanin production of cut sweet pea floret by sucrose may involve anthocyanin biosynthetic gene expressions. Furthermore, anthocyanin concentration in sweet pea florets supplied with sucrose alone was greater than spikes treated with STS followed by sucrose (Fig. 3). In our study, the anthocyanin concentration is very high in sweet pea florets, and it may be linked with senescence processes; *e.g*., orchid flowers change from white to pink or blue during senescence (Chadwick *et al*. 1980). In petunias, flower longevity was inversely correlated with anthocyanin content (Ferrante *et al*. 2006). Thus, the sucrose-induced stimulation of anthocyanin production promotes pigmentation of petal colors in some cut flowers such as Eustoma (Ichimura and Korenaga 1998) and sweet pea (Ichimura and Hiraya 1999).

Conclusion: According to these results it was possible to extend vase life of sweet pea cut flowers using HQS plus sucrose for 12 h by causing delayed senescence. This is shown by the delayed mass loss, improve water uptake and further to probe their role in processes such as Chl and carbohydrate metabolism which are connected to cut flower longevity and quality of sweet pea, a major concern for growers as well as exporters. Our additional aim was to use Suc+HQS solution as a commercial cut flower preservative for prolonging the vase life and post harvest quality of sweet pea cut flowers.

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