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Research Report

Effects of Simulated In-Transit Vibration on the Vase Life and Post-Harvest Characteristics of Cut Rose Flowers

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Abstract. We examined whether exposure to vibration during transport affects the quality of cut roses. Using a laboratory vibration simulator, in-transit vibration of 7.5 or 10 Hz was applied to two cut rose cultivars ('Polar Star' and 'Revival') at three positions within a compartmented storage bin (top, middle, and bottom) for 10 or 15 min. Post-harvest characteristics of the cut flowers were measured in a test room. We observed that in both cultivars, vibration significantly reduced vase life (VL), decreased relative fresh weight (RFW), and increased flower opening rate (FOR). No significant differences were observed between vibration frequencies, positions, or durations in 'Polar Star' with respect to VL. Furthermore, we applied a simulated vibration of 10 Hz to three cut rose cultivars ('Polar Star', 'Magic Red', and 'Full House'). We observed that 'Polar Star' was more sensitive to vibration damage than the other two cultivars. Pulse treatments coupled with the exogenous application of silver thiosulfate (STS), an ethylene action inhibitor, were applied to 'Polar Star' before and after vibration. Independent of the concentration used and time of application, STS significantly decreased FOR, water uptake, water loss, and increased RFW. However, only 1 mM STS applied before vibration extended VL compared to non-vibrated control VL. Thus, vibration during transport could shorten the VL of cut rose flowers. The amount of vibration damage in cut rose flowers is cultivar dependent. Taken together, our data suggest that ethylene underlies the negative impact of vibration on post-harvest characteristics of cut rose flowers. Application of ethylene action inhibitors before transit could reduce or prevent the vibration effects on the post-harvest quality of sensitive cut rose cultivars.

***Additional key words*:** Cut flower, Mechanical damage, Silver thiosulfate, Water relations

Introduction

The vase life (VL) of cut rose flowers is affected by various factors, such as pre-harvest growing conditions, post-harvest handling, storage, and transportation (Fanourakis et al., 2013; Reid and Jiang, 2012). These factors may result in a negative water balance (van Doorn, 2012), higher respiration, and faster flower senescence (Reid and Jiang, 2012).

Long distance transport to markets imposes several negative effects on the post-harvest properties of cut flowers. The effects of altered temperature during transport of cut flowers on VL and quality have been extensively investigated in simulations (Çelikel and Reid, 2002b; Reid, 1999; Rudnicki et al., 1991), as have wet and dry transportation (Cevallos and Reid, 2001; Le Masson and Nowak, 1981; Macnish et al., 2009), and rapid vs. slow transport (Leonard et al., 2011). Respiration, bend neck, and weight loss during dry transport of cut flowers all increase as storage temperatures rise in simulated transport (Çelikel and Reid, 2004; Çelikel et al., 2010; Çelikel and Reid, 2002a; Çelikel and Reid, 2002b; Rudnicki et al., 1991). Therefore, maintaining low temperatures during commercial handling and transport is recommended. Further, hydration of cut flowers during handling and transport has long been used to restore flower turgidity, opening, and petal expansion (Evans and Reid, 1988; Mayak and Halevy, 1971; van Doorn, 2012). However, some researchers proposed dry handling of cut flowers combined with refrigeration, as this treatment reduced transport-related damage, risk of bacterial growth, occlusion of flower stems and transport and handling costs (Çelikel et al., 2010; Cevallos and Reid, 2001; Macnish et al., 2009).

The majority of fresh cut flowers sold in Iran are produced in the northern parts of the country and distributed to retailers countrywide via truck transport. Previous research

has shown that truck transport on Iranian roads produces vibrations of between 7.5 and 10 Hz at a constant acceleration of 0.5 g (1 g = 9.81 $m \cdot s^{-2}$) (Shahbazi et al., 2010). Many researchers have addressed fruit and vegetable damage caused by vibration during transport (Acıcan et al., 2007; Barchi et al., 2002; Fischer et al., 1990; Ishikawa et al., 2009; Shahbazi et al., 2010). However, there is limited knowledge of the effects of vibration or shaking on the quality of cut flowers during truck transport. Nam et al. (1997) showed that vibration increased ethylene production in *Cymbidium* flowers and that aminoethoxyvinylglycine (AVG) treatment prior to the vibration reduced ethylene production. Senescence of *Cymbidium* flowers is largely dependent on ethylene (Arditti et al., 1973). However, the VL and post-harvest quality of other commercially important cut flowers (such as roses) subjected to vibration remain unclear. Therefore, we designed experiments to elucidate the effect of simulated in-transit vibration on the post-harvest quality responses of several cut rose cultivars and to physiologically explain the effects.

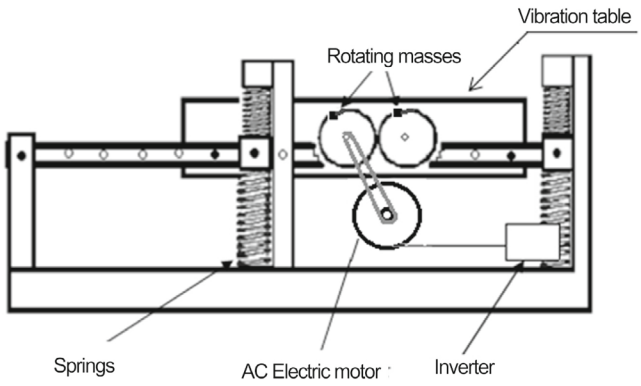

Fig. 1. Laboratory simulator used in the current study to simulate the vibration of the truck-bed under road conditions. A container full of flower stems was fixed on an oscillating table and excitation was effected by means of eccentric weights rotating in opposite directions. The magnitude and angular velocity of the rotating masses could be changed and the dynamic states (displacement, acceleration) of the individual layers could be examined.

Materials and Methods

Experiment 1

Cut rose flowers (*Rosa hybrida* L. 'Polar Star' and 'Revival') were obtained from a local commercial grower in Khorramabad, Iran. Flower stems were harvested at normal harvest maturity (sepal starting to reflex) in the morning, and transported dry to the laboratory of Lorestan University (a distance of 5 km). Stems were re-cut under fresh tap water and placed in buckets of fresh tap water and kept in a cold room at 4 ± 1°C overnight to gain maximum relative water content. Thereafter, simulated in-transit vibration at two frequencies (7.5 and 10 Hz), three positions within a compartmented storage bin (bottom, middle, and top bins), and at two vibration durations (10 and 15 min) were applied to flower stems. Control group flowers were kept under the same conditions without vibration.

Experiment 2

The same procedure described in experiment 1 was applied to three cut rose cultivars ('Polar Star', 'Magic Red', and 'Full House') with a simulated vibration at 10 Hz in the bottom of the bin for 10 minutes.

Experiment 3

A 60-min pulse treatment with 0, 0.5, or 1 mM silver thiosulfate (STS) was applied to 'Polar Star' before or after simulated vibration at 10 Hz in the bottom of the bin for 10 minutes.

Vibration Simulation

The vibration simulator used in this study was similar to the one described earlier (O'Brien and Guillou, 1969; Oeguet et al., 1999; Shahbazi et al., 2010; Vursavuş and ÖzgÜven, 2004). The laboratory vibration simulator (Fig. 1), powered by an electric motor (3.0 kW and 3000 rpm), was used to provide frequencies covering the range of truck-beds under road conditions. Undampened, forced vibrations were obtained by an actuating system that included adjustable weights on two counter-rotating shafts attached to the table revolving in opposite directions, providing vertical vibrations only. The speed of the electric motor was adjusted by means of a 4.0 kW speed control unit (inverter). The frequency of the table was obtained based on the revolutions of the electric motor. Acceleration of the vibration simulator table was directly measured using a piezoelectric accelerometer (VB-8213-Lutron, Taiwan).

To carry out the vibration simulation, a compartmented wooden bin of flower stems was placed on the vibration table as they would normally be loaded onto a truck. Flower stems were placed at the bottom, middle, and top positions corresponding to 0, 40, and 80 cm in height, respectively.

Flowers were dry during vibration simulation and the environmental conditions in the vibration simulation room were a temperature of 20 ± 2°C and 60% relative humidity. Vibration frequencies of 7.5 and 10 Hz at a constant acceleration of 0.5 g (1 g=9.81 $m \cdot s^{-2}$) were used for vibration simulation. Previous research has shown that the above vibration frequencies and acceleration were the most common measured frequencies of a truck-bed under Iranian road conditions (Shahbazi et al., 2010). Vibration durations were 10 and 15 minutes to simulate average transport conditions over 330 and 500 km distances, respectively (Acıcan et al., 2007; Shahbazi et al., 2010).

Measurements of Vase Life and Post-harvest Characteristics

After vibration treatments, stems were re-cut under water to a stem-length of 45 cm and all leaves except the uppermost three were removed. Single flower stems were kept in 500 ml conical flasks, each containing 5 $g \cdot L^{-1}$ sucrose and 20 $\mu L \cdot L^{-1}$ chlorine using sodium hypochlorite (130 $mL \cdot L^{-1}$ active chlorine, Acros Organics N.V., NJ). Distilled water was used for vase-solution preparations. The mouths of the flasks were covered with aluminum foil to prevent evaporative water loss. The environmental conditions in the test room for vase life evaluation were a temperature of 20 ± 2°C, 60% relative humidity, and 12-h photoperiod under 10 $\mu mol \cdot m^{-2} \cdot s^{-1}$ irradiance provided by cool-white fluorescence lamps.

Flower stems were briefly removed from vases and weighed daily to calculate relative fresh weight (RFW). RFW was calculated using the following equation:

$$RFW\ (\%) = (FW_t / FW_0) \times 100$$

Where FW_t = weight of flower (g) at 0-10 days after vase incubation, FW_0= weight of flower (g) at day 0.

Vases containing water or solution were also weighed separately when flowers were weighed to determine the water uptake and water loss. Water uptake and water loss were calculated using the following equations:

$$\text{Water uptake } (ml \cdot g_{FW}^{-1} \cdot d^{-1}) = (V_{t-1} - V_t) / FW_0$$

Where:

V_t= weight of vase containing water or solution (g) at days 1-10, V_{t-1}= weight of vase containing water or solution (g) at the previous day, FW_0= weight of flower (g) at day 0.

$$\text{Water loss } (ml \cdot g_{FW}^{-1} \cdot d^{-1}) = (T_{t-1} - T_t) / FW_0$$

Where:

T_t= weight of flower plus vase containing water or solution (g) at days 1-10, T_{t-1}= the weight of flower plus vase containing water or solution (g) at the previous day, FW_0= the weight of flower (g) at day 0.

Longevity of flowers was recorded as VL (d), from the time the cut flowers were placed in conical flasks (day 0). Flowers were considered to be at the end of their VL when the flowers either showed bent necks, wilting of outer petals, or bluing of petals (Kumar et al., 2008; Pompodakis and Joyce, 2003).

Flower opening rate was calculated using the following equation:

$$\text{Flower opening rate } (mm \cdot d^{-1}) = (MFS - IFS)/T_{MFS}$$

Where:

MFS= maximum flower size (mm), IFS= initial flower size (mm), T_{MFS}= the time of maximum flower size (d).

Statistical Analysis

Each experiment was carried out with at least three replications. For statistical comparison, analyses of variance (ANOVA) were done. In experiments 1 and 3, post-test comparisons for VL, FOR, water uptake, and water loss were done using Tukey's HSD test ($p < 0.05$). In experiment 2, a Student's *t*-test was used for mean comparison ($p < 0.05$) in each cultivar. MSTAT-C software (Michigan State University, East Lansing, MI, USA) and GraphPad Prism 4 for Windows (GraphPad Software, San Diego, CA, USA) were used for all statistical analyses.

Results

Experiment 1

Vibration significantly decreased the VL of both cut rose cultivars (Table 1). In 'Revival', vibration tended to decrease the VL of cut flowers in all treatments. However, the effect of vibration was significant only in some treatments, namely, stems vibrated with 7.5 Hz frequency for 15 minutes at the middle position of the bin, and stems vibrated with 10 Hz frequency for 15 minutes at the bottom or top positions of the bin. In 'Polar Star' all vibration treatments significantly decreased the VL of cut flowers by two days compared with the control, except in stems exposed to a 10 Hz vibration for 15 minutes at the top positions of the bin. We observed no significant difference among vibration frequencies, positions, or durations within the treatment groups.

Vibration significantly increased the FOR of both cut rose cultivars (Table 1). Independent of vibration frequency and duration, cut flowers placed on the bottom of the bin tended to show higher FOR, especially in 'Polar Star'. Table 2 shows the effects of vibration frequency on VL and FOR of 'Revival' and 'Polar Star'. Both vibration frequencies similarly reduced VL and increased FOR in both cultivars. There were significant differences in daily changes in RFW of cut flowers in both cultivars (Figs 2 and 3). The RFW of cut flowers increased within the first 2-3 days and then decreased gradually. In both cultivars, vibrated cut flowers showed a faster decrease in RFW as compared to the non-vibrated control (Figs 2 and 3). We conclude that vibration during transport shortens VL, increases FOR, and decreases RFW of cut rose flowers.

Experiment 2

Table 3 shows the results of vibration treatments on VL and FOR of three cut rose cultivars, 'Magic Red', 'Full House' and 'Polar Star'. Vibrated cut flowers tended to show lower VLs and greater FORs compared with controls. However,

Table 1. Vase life and flower opening rate of cut rose flowers ('Revival' and 'Polar Star') vibrated at two frequencies (7.5 and 10 Hz), three cut flower positions in the bin [bottom (0 cm height), middle (40 cm height), and top (80 cm height)], and two vibration durations (10 and 15 min) compared with controls

Vibration frequency (Hz)	Vibration duration (min)	Position in the bin (cm)	Vase life (d)		Flower opening rate ($mm \cdot d^{-1}$)	
			'Revival'	'Polar Star'	'Revival'	'Polar Star'
7.5	10	0	10.7±0.7 ab	7.7±0.3 b	5.60±1.28 abc	8.47±0.39 ab
		40	10.0±0.6 ab	7.7±0.3 b	5.25±0.98 abc	5.87±0.62 bc
		80	10.7±0.7 ab	7.7±0.3 b	5.45±0.49 abc	6.42±0.65 bc
	15	0	10.7±0.7 ab	8.3±0.3 b	4.75±1.09 abc	9.58±0.93 a
		40	9.0±0.6 b	8.3±0.3 b	4.66±0.22 abc	7.66±0.43 abc
		80	10.7±0.7 ab	8.3±0.3 b	3.60±0.13 bc	6.45±0.88 bc
10	10	0	9.3±0.3 ab	7.7±0.3 b	3.54±0.07 bc	8.54±0.41 ab
		40	10.7±0.3 ab	8.3±0.3 b	3.79±0.14 abc	8.18±0.16 ab
		80	10.3±0.3 ab	8.3±0.3 b	6.67±0.68 ab	7.42±0.66 abc
	15	0	9.0±0.6 b	8.3±0.3 b	7.42±0.60 a	6.59±0.51 abc
		40	10.3±0.3 ab	8.3±0.3 b	5.89±1.24 abc	5.75±0.76 bc
		80	9.0±0.6 b	8.7±0.3 ab	3.83±0.35 abc	6.02±0.19 bc
Control			12.0±0.6 a	10.3±0.3 a	2.78±0.42 c	4.72±0.49 c
p (cultivar)			< 0.0001		< 0.0001	
p (vibration)			0.0001		0.0001	
p (cultivar × vibration)			0.0756		0.0002	

† Data are the means of three replicates ± SEM.
†† Different letters in each column show significant difference among means according to Tukey's test ($p < 0.05$).

Table 2. Effects of vibration frequency on the vase life and flower opening rate of cut rose flowers ('Revival' and 'Polar Star')

Vibration frequency (Hz)	Vase life (d)		Flower opening rate ($mm \cdot d^{-1}$)	
	'Revival'	'Polar Star'	'Revival'	'Polar Star'
7.5	10.3±0.3 b	8.0±0.2 b	4.89±0.22 a	7.41±0.10 a
10.0	9.8±0.1 b	8.3±0.1 b	5.19±0.18 a	7.08±0.23 a
Control	12.0±0.6 a	10.3±0.3 a	2.78±0.42 b	4.72±0.49 b
p (cultivar)	< 0.0001		< 0.0001	
p (vibration frequency)	< 0.0001		< 0.0001	
p (cultivar × vibration frequency)	0.462		0.543	

† Data are the means of three replicates ± SEM.
†† Different letters in each column show significant difference among means according to Tukey's test ($p < 0.05$).

Table 3. Vase life and flower opening rate of cut rose flowers ('Magic Red', 'Full House' and 'Polar Star') vibrated at 10 Hz in the bottom of the bin for 10 min compared with controls

Treatment	Vase life (d)			Flower opening rate ($mm \cdot d^{-1}$)		
	'Magic Red'	'Full House'	'Polar Star'	'Magic Red'	'Full House'	'Polar Star'
Control	6.8±0.3 a	5.5±0.3 a	8.3±0.3 a	2.25±0.59 a	4.62±0.77 a	4.64±0.36 b
Vibrated	6.0±0.6 a	5.3±0.3 a	6.3±0.3 b	5.27±1.23 a	5.39±0.58 a	7.05±0.46 a
p	0.278	0.537	0.001	0.069	0.454	0.006

† Data are the means of four replicates ± SEM.
†† Different letters in each column show significant difference between means according to Student t-test ($p < 0.05$).

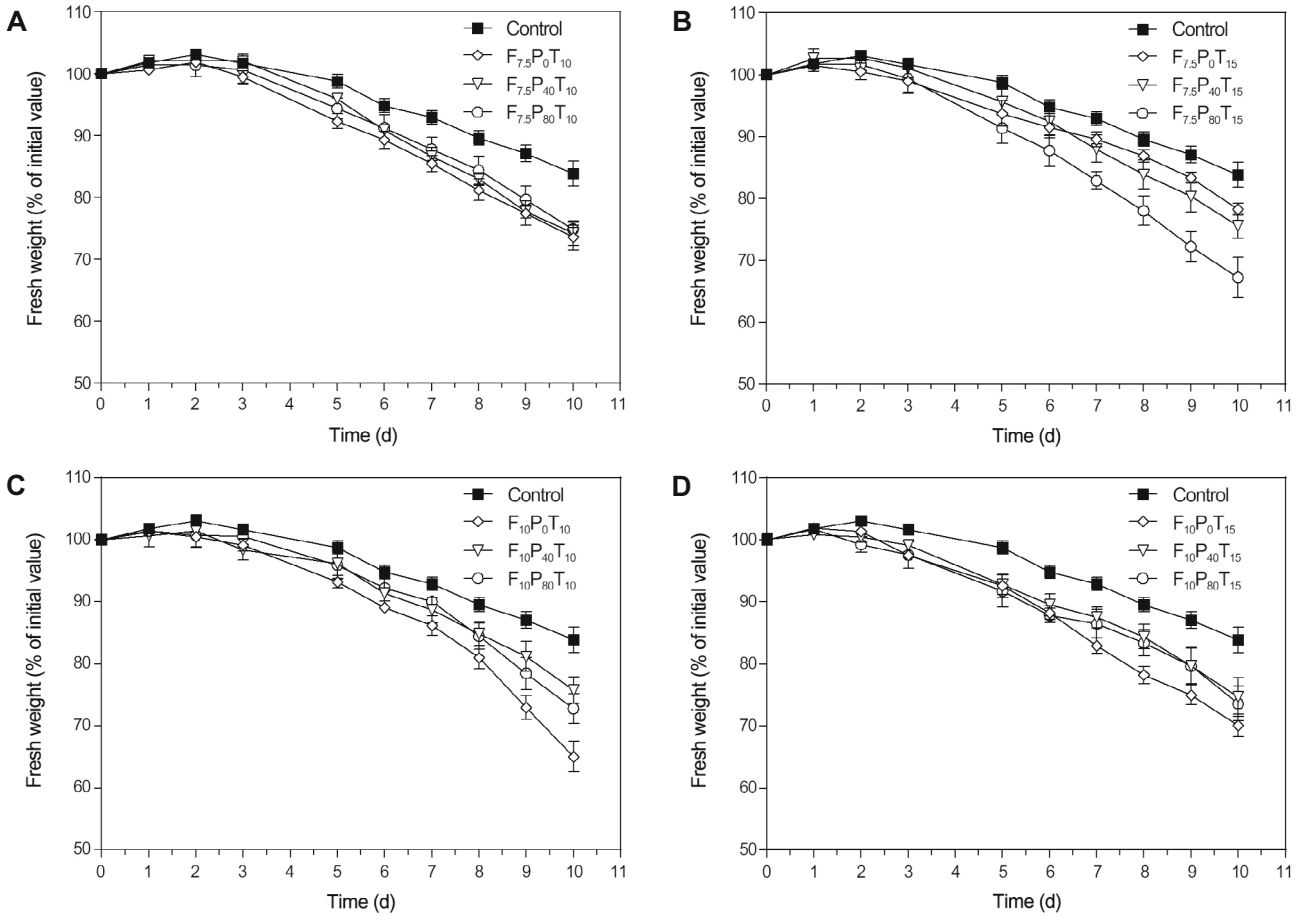

Fig. 2. Daily changes in the relative fresh weight (RFW) of cut rose flowers 'Revival' vibrated with two frequencies (7.5 and 10 Hz), three cut flower positions in the bin [bottom (0 cm height), middle (40 cm height), and top (80 cm height)], and two vibration durations (10 and 15 min) compared with the control. (A) RFW of flowers vibrated with 7.5 Hz for 10 min at the bottom, middle, and top of the bin compared with the control. (B) RFW of flowers vibrated with 7.5 Hz for 15 min at the bottom, middle and top of the bin compared with the control. (C) RFW of flowers vibrated with 10 Hz for 10 min at the bottom, middle and top of the bin compared with the control. (D) RFW of flowers vibrated with 10 Hz for 15 min at the bottom, middle and top of the bin compared with the control. Data are the means of three replicates ± SEM. Bars indicate standard errors.

the effects were only significant in 'Polar Star'. Furthermore, the vibrated cut flowers of all three cultivars tended to show a faster decrease in RFW compared to those of the controls (Fig. 4). The effects in 'Polar Star' were more pronounced and the RFW of vibrated cut flowers significantly declined from day five until the end of the experiment (Fig. 4C). The effects of vibration on water uptake of all three cultivars were not significant (Table 4). Vibrated cut flowers tended to show greater water loss than the controls. However, the effects were only significant in 'Polar Star' (Table 4).

Experiment 3

Treatment with 1 mM STS extended the VL for about one day compared with 0 mM STS under non-vibrating conditions (Table 5). As observed in previous experiments, vibration significantly decreased VL. Vibrated cut flowers treated with STS tended to have a larger VL. The observed effect was only significant in treatment with 1 mM STS before vibration. The VL of vibrated cut flowers treated with 1 mM STS before vibration was similar to that in control non-vibrated cut flowers. Vibration significantly increased the FOR (Table 5). Independent of concentration, time of STS application, or vibration, pulse treatment with STS significantly decreased the FOR.

Significant differences were observed in relative fresh weight (RFW) of the cut flowers (Fig. 5). The RFW of cut flowers increased in the first three days and then gradually decreased. Vibrated cut flowers showed a faster decrease in RFW from day five until the end of the vase experiment relative to control flowers. Independent of concentration and time of STS application, pulse treatment with STS significantly decreased the RFW loss in cut flowers. Vibration significantly increased water uptake and loss (Table 6). Regardless of concentration and time of STS application, pulse treatment

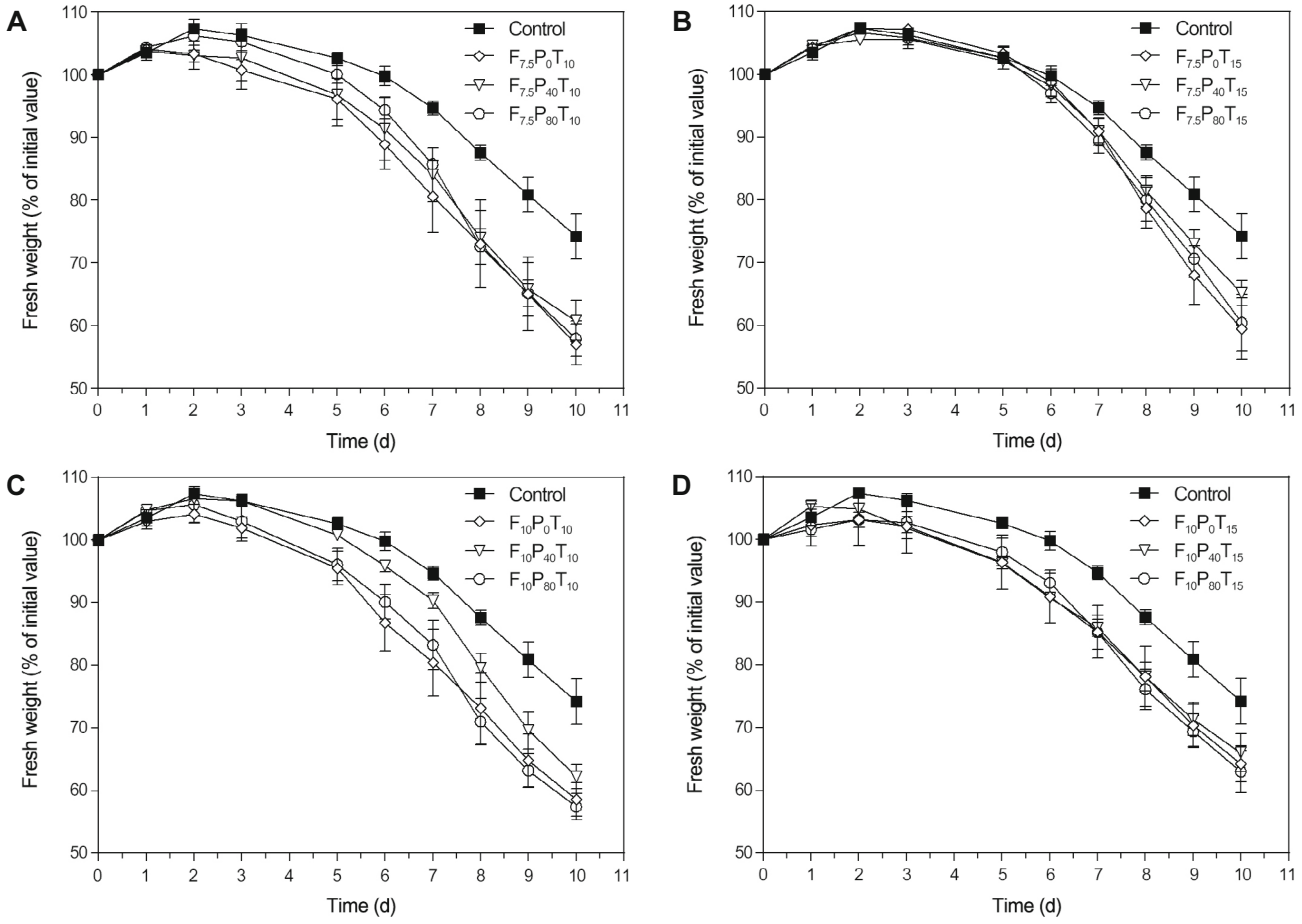

Fig. 3. Daily changes in relative fresh weight (RFW) of cut rose flowers 'Polar Star' vibrated with two frequencies (7.5 and 10 Hz), three cut flower positions in the bin [bottom (0 cm height), middle (40 cm height), and top (80 cm height)] and two vibration durations (10 and 15 min) compared with the control. (A) RFW of flowers vibrated with 7.5 Hz for 10 min at the bottom, middle, and top of the bin compared with the control. (B) RFW of flowers vibrated at 7.5 Hz for 15 min at the bottom, middle, and top of the bin compared with the control. (C) RFW of flowers vibrated with 10 Hz for 10 min at the bottom, middle, and top of the bin compared with the control. (D) RFW of flowers vibrated with 10 Hz for 15 min at the bottom, middle, and top of the bin compared with the control. Data are the means of three replicates ± SEM. Bars indicate standard errors.

with STS significantly decreased water uptake and water loss (Table 6).

Discussion

The results of the current research showed that vibration reduced the VL by 2–3 days in both 'Revival' and 'Polar Star' roses. Shorter VL of cut flowers during transit has been reported previously, and was attributed to factors such as poor temperature management (Çelikel and Reid, 2004; Çelikel et al., 2010; Çelikel and Reid, 2002b; Leonard et al., 2011; Reid, 1999; Rudnicki et al., 1991) or a negative water balance (Cevallos and Reid, 2001; Le Masson and Nowak, 1981; van Doorn, 2012). We undertook the present series of experiments because research addressing the effects of vibration on VL in cut flowers is scarce. Nam et al. (1997) showed that vibration reduced post-harvest quality of *Cymbidium*, consistent with our results. Our findings are consistent with those of other studies that showed that vibration reduced the shelf life of various fruits and vegetables (Ishikawa et al., 2009; Olorunda and Tung, 1985; van Zeebroeck et al., 2007).

Sensitivity of cut flowers to vibration varied considerably among the tested cultivars. Our results show that VL and water relations of both 'Revival' and 'Polar Star' were affected by vibration treatment. However, the effects were more pronounced in 'Polar Star'. Further, 'Polar Star' was more sensitive to vibration damage than 'Magic Red' and 'Full House'. Taken together, our findings highlight the potential variation in tolerance to vibration damage among cut rose cultivars.

In an attempt to reduce the negative impacts of vibration on VL, we performed pulse treatments with STS, an ethylene action inhibitor. We found that STS alleviated the negative effects of vibration on the post-harvest quality of

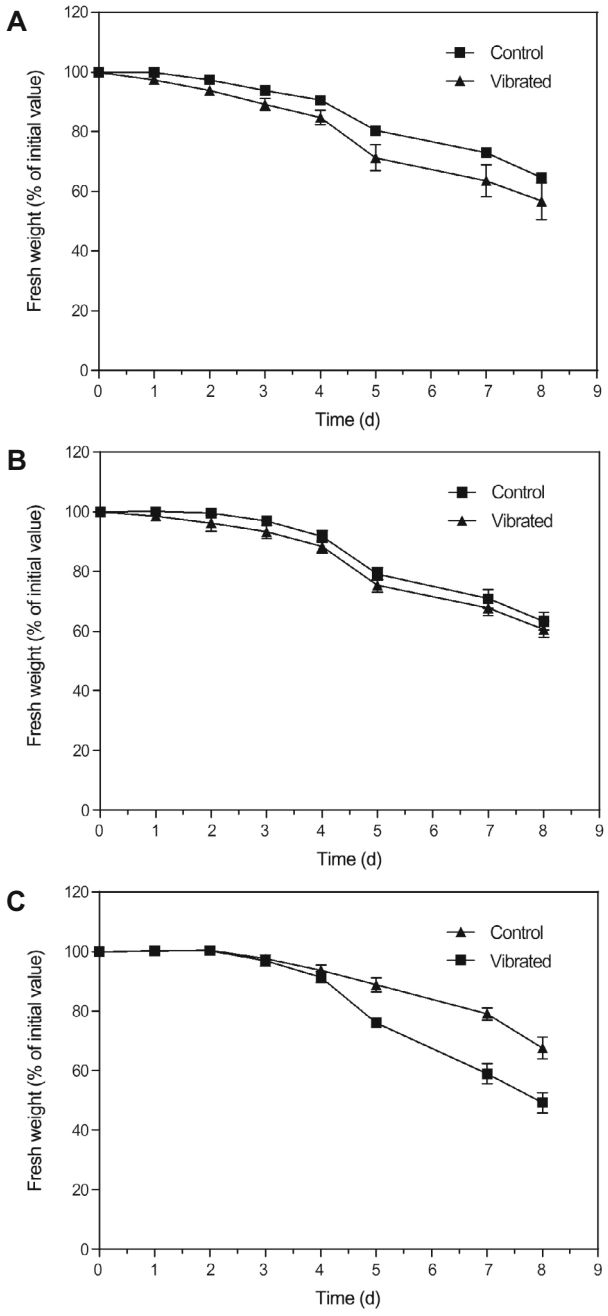

Fig. 4. Daily changes in relative fresh weight of three cut rose flowers, (A) 'Magic Red', (B) 'Full House', and (C) 'Polar Star', vibrated at 10 Hz in the bottom of the bin for 10 min compared with controls. Data are the means of four replicates ± SEM. Bars indicate standard errors.

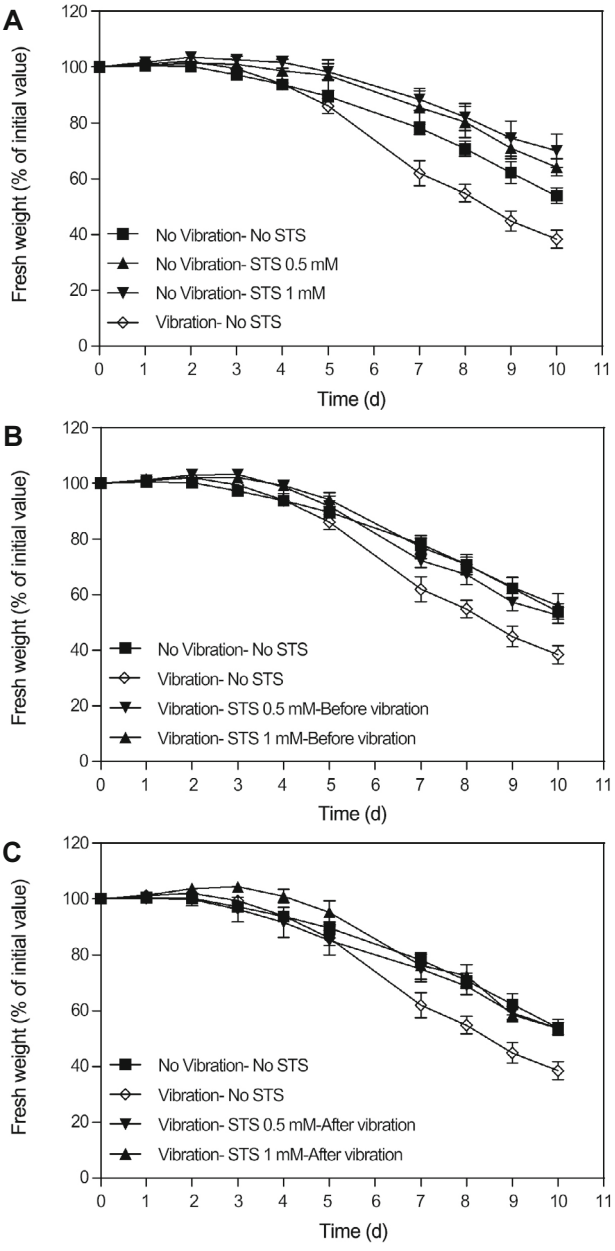

Fig. 5. Daily changes in relative fresh weight (RFW) of cut rose flowers 'Polar Star' treated with silver thiosulfate (STS) for 60 min before and after the simulated vibration of 10 Hz at the bottom of the bin for 10 min compared with controls. (A) RFW of vibrated cut flowers treated with 0 mM STS and control (non-vibrated) flowers treated with 0, 0.5, and 1 mM STS. (B) RFW of control flowers treated with 0 mM STS and vibrated flowers treated with 0, 0.5 and 1 mM STS before vibration. (C) RFW of control flowers treated with 0 mM STS and vibrated flowers treated with 0, 0.5, and 1 mM STS after vibration. Data are the means of four replicates ± SEM. Bars indicate standard errors.

cut roses. Ethylene has received the most attention of all plant hormones with respect to mechanical stress (Khan, 2006; Mitchell and Myers, 1995). Treatments known to inhibit ethylene action, such as silver containing compounds, prevent certain plant responses to mechanical stresses (Boyer et al., 1983), and they have been widely used to maintain the quality of cut flowers (Scariot et al., 2014). Our finding is consistent with a previous study in which application of AVG, an ethylene biosynthesis inhibitor, reduced the negative effects of simulated vibration on *Cymbidium* quality (Nam et al., 1997).

Besides the inhibition of ethylene-mediated processes, such as flower senescence and abscission (Reid and Wu,

Table 4. Water uptake and water loss of cut rose flowers ('Magic Red', 'Full House' and 'Polar Star') vibrated at 10 Hz at the bottom of bin for 10 min compared with controls

Treatment	Water uptake (ml·gFW^{-1}·d^{-1})			Water loss (ml·gFW^{-1}·d^{-1})		
	'Magic Red'	'Full House'	'Polar Star'	'Magic Red'	'Full House'	'Polar Star'
Control	0.217±0.025a	0.214±0.029a	0.315±0.008a	0.209±0.018a	0.216±0.026a	0.225±0.004b
Vibrated	0.251±0.033a	0.201±0.020a	0.300±0.043a	0.271±0.032a	0.247±0.026a	0.440±0.077a
p	0.445	0.717	0.738	0.144	0.439	0.033

† Data are the means of four replicates ± SEM.
†† Different letters in each column show significant difference between means according to Student t-test ($p < 0.05$).

Table 5. Vase life and flower opening rate of cut rose flowers ('Polar Star') vibrated at 10 Hz in the bottom of the bin for 10 min compared with controls

Vibration	STS (mM)	Time of STS treatment	Vase life (d)	Flower opening rate (mm·d^{-1})
Control	0	-	8.3±0.3 ab	5.50±0.14 b
	0.5	-	8.8±0.3 a	3.77±0.12 c
	1	-	9.3±0.3 a	3.81±0.16 c
Vibrated	0	-	6.5±0.3 c	6.68±0.33 a
	0.5	Before vibration	7.3±0.3 bc	5.51±0.17 b
	0.5	After vibration	6.8±0.3 c	5.44±0.12 b
	1	Before vibration	8.3±0.3 ab	5.21±0.03 b
	1	After vibration	7.3±0.3 bc	5.61±0.10 b
p			< 0.0001	< 0.0001

† Data are the means of four replicates ± SEM.
†† Different letters in each column show significant difference among means according to Tukey's test ($p < 0.05$).
††† As the results of STS treatments before and after vibration were the same for controls, only the data of before vibration are presented.

Table 6. Water uptake and water loss of cut rose flowers ('Polar Star') vibrated at 10 Hz in the bottom of the bin for 10 min compared with controls

Vibration	STS (mM)	Time of STS treatment	Water uptake (ml·gFW^{-1}·d^{-1})	Water loss (ml·gFW^{-1}·d^{-1})
Control	0	-	0.288±0.007 b	0.334±0.012 b
	0.5	-	0.290±0.007 b	0.329±0.014 b
	1	-	0.276±0.009 b	0.300±0.007 c
Vibrated	0	-	0.319±0.012 a	0.369±0.007 a
	0.5	Before vibration	0.282±0.008 b	0.317±0.008 bc
	0.5	After vibration	0.267±0.011 b	0.314±0.013 bc
	1	Before vibration	0.286±0.012 b	0.330±0.010 b
	1	After vibration	0.291±0.006 b	0.329±0.007 b
p			0.0390	0.0057

† Data are the means of four replicates ± SEM.
†† Different letters in each column show significant difference among means according to Tukey's test ($p < 0.05$).
††† As the results of STS treatments before and after vibration were the same for controls, only the data of before vibration are presented.

1992; Scariot et al., 2014), the positive effect of silver containing compounds in cut flowers has also been attributed to improving water balance (Hutchinson et al., 2004; Lü et al., 2010). Water balance is a major factor influencing post-harvest cut flower quality. It is affected by rates of water uptake and water loss. When the rate of water loss exceeds the rate of water uptake, negative water balance occurs, wilting develops, and flower longevity is reduced (van Doorn, 2012). Silver containing compounds inhibit bacterial growth in the vase solution and thus increase water uptake in cut stems (van

Doorn, 2012). However, in the current study, pulse treatments with both 0.5 and 1 mM STS improved water balance through reducing water uptake, water loss, and loss of fresh weight when applied both before and after vibration treatments. Water loss (transpiration) occurs mainly through stomata. Moreover, transpiration is the main driving force for water uptake via xylem, and a reduction of transpiration results in lower water uptake. There is some evidence that ethylene increases stomatal apertures (Levitt et al., 1987; Tanaka et al., 2005; Tanaka et al., 2006) and inhibitors of ethylene have the opposite effect (Levitt et al., 1987; Merritt et al., 2001). Recent research on cut rose flowers have tested this using direct stomatal aperture and transpiration rate measurements of silver nano-particle pulse-treated leaves (Lü et al., 2010). The effect of silver treatment on stomatal closure in cut rose leaves has been related to its suppression effect on aquaporins (Lü et al., 2010). Aquaporins are primary channels of water transport across biological membranes and believed to play a role in regulating stomatal aperture (Fraysse et al., 2005; Sarda et al., 1997). In addition, it has been shown that ethylene increases plasma membrane permeability by enhancing aquaporin activity, presumably due to the phosphorylation of aquaporins (Kamaluddin and Zwiazek, 2002; Woltering, 1990).

According to our results, vibration caused a faster FOR in 'Polar Star' and 'Revival', while 'Magic Red' and 'Full House' were not affected. Moreover, application of 0.5 and 1 mM STS, both before and after vibration, reduced the FOR in 'Polar Star'. It has been shown that flower opening in response to ethylene is cultivar-dependent and in this respect, rose cultivars have been divided into three groups: opening-inhibited, opening-stimulated, and opening not affected (Reid et al., 1989; Yamamoto et al., 1994). Different responses of flower opening to ethylene in different cultivars have been attributed to different expression levels of ethylene receptor genes (Tan et al., 2006; Xue et al., 2008).

From the observations in our study, the following can be concluded. First, the effects of vibration on negative water balance and shorter VL could be mediated by ethylene action. Second, the shorter VL induced by vibration was affected by both STS concentration and time of STS application. Third, although STS application after vibration improved water balance and decreased FOR, it was too late to prevent all of the negative effects of vibration and resulted in a shorter VL. Only application of 1 mM STS before vibration extended the VL to the control value. One explanation could be that the ethylene produced during and/or after vibration initiates senescence processes in flowers before STS application/action. Finally, 'Polar Star' has a higher sensitivity to vibration compared with other tested cultivars and its response to STS treatment seems to be related to its higher sensitivity to ethylene.

Conclusion

The results of this research have provided further support for the effects of mechanical damage on horticultural crops during road transport. We conclude that (1) vibration during transport shortens the VL of cut rose flowers; (2) the amount of vibration damage in cut rose flowers is cultivar dependent; (3) ethylene could be involved in the negative effects of vibration on the post-harvest characteristics of cut rose flowers; and (4) application of ethylene inhibitors before transportation reduced or prevented the effects of vibration on postharvest cut flower quality.

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