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Cold storage and flower keeping quality of cut tuberose (*Polianthes tuberosa* L.)

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SUMMARY
The vase life and floret opening of cut tuberose inflorescences were significantly decreased by cold storage. The ideal storage temperature was found to be 0°C for short durations because even storage at 2°C for only 3 d significantly decreased floret opening and the vase life of stored inflorescences. There was no significant difference between "wet" storage in a preservative solution (250 ppm 8-hydroxyquinoline citrate, 2% sucrose) and "dry" storage (spikes wrapped in polythene film to reduce water loss). Pre-storage pulsing with a 20% sucrose solution (containing HQC) significantly improved the vase life and opening of cold-stored spikes. The vase life and floret opening of spikes treated in this way were equal, after 6 d of storage at 2°C, to those of fresh cut inflorescences. The end of the vase life of cut tuberose spikes coincided with the time taken to return to their initial fresh weight. Cold storage resulted in a pronounced increase in ethylene production by the florets, particularly by immature buds. Ethylene treatment of fresh cut tuberose spikes reduced floret opening, but ethylene induced by cold storage did not appear to be the cause of reduced floret opening. Pretreatment of spikes with STS eliminated the effects of exogenous ethylene on fresh spikes, but had no effect on the reduced vase life of cold-stored flowers and substantially increased ethylene production by their florets. Ethylene production by florets of sucrose-pulsed spikes was similar to that of the controls. It appears that the shortened vase life of cold-stored tuberose is not due to the induction of ethylene biosynthesis.

Tuberose (*Polianthes tuberosa* L.), a member of the *Agavaceae* native to Mexico, has long been cherished for the aromatic oils extracted from its fragrant white flowers (Trueblood, 1973). It has recently gained popularity as a cut flower and in a number of countries including Kenya, India and Mexico it is grown commercially for export markets in the USA, Europe and Japan.

Tuberose inflorescences (spikes) bear 10–20 pairs of florets which open acropetally. Commercially, spikes 60–90 cm long are harvested when two or three basal florets are open. Fewer than 50% of the buds normally open after harvest and florets and buds usually abscind after only a few days in the vase. Postharvest performance is worse in tuberose which have been shipped to distant markets (Waithaka, unpublished). Since tuberose originated from the sub-tropics, this loss of quality might be due to chilling injury induced by exposure to low but non-freezing temperatures during marketing. Alternatively, it might be the result of postharvest desiccation, or improper temperature management. In cut roses, cool storage has been reported to induce ethylene biosynthesis which negatively affects opening and vase life of the flowers (Mor *et al*., 1989).

We report here an examination of the effects of temperature, storage duration, and pretreatments on the vase life and opening of cut tubercose influorescences.

MATERIALS AND METHODS

Plant material

Cut tuberose spikes were obtained from commercial growers in Watsonville, California. Inflorescences were harvested with two or three open florets, immediately placed in water or in vase preservative, containing 250 ppm HQC (8-hydroxyquinoline citrate) and 2% sucrose, and transported to Davis. There, they were trimmed to a length of 60 cm prior to use in experiments.

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Prestorage treatments

Cut spikes were "pulsed" with solution containing 20% sucrose and 250 ppm HQC for 24 h, or 1 mM STS (silver thiosulfate) containing 250 ppm HQC for 2 h. This latter treatment provided approximately 1 mol of silver per inflorescence.

Cold storage

The effects of storage temperatures at 0, 5, 10 and 15°C and durations of 4, 8, 12 and 16 d on flower quality and longevity were studied. Inflorescences were wrapped in soft paper, enclosed in polyethylene sheet to reduce water loss and placed in closed cartons. The wet-stored spikes were placed in a bucket with their bases in preservative solution. Wet or dry cold storage was at 20°C. After cold storage, spikes wer unwrapped, weighed, recut and placed in vase preservative in a controlled environment maintained at 20°C, 60% relative humidity, and a 12 h daylength under cool white fluorescent lighting at an intensity of 15 mol m^2sec^{-1}. Five spikes per treatment replicated six times, were used in the pre-storage and cold storage experiments.

Vase life and floret opening

The vase life and floret opening of cut inflorescences were considered terminated when the number of

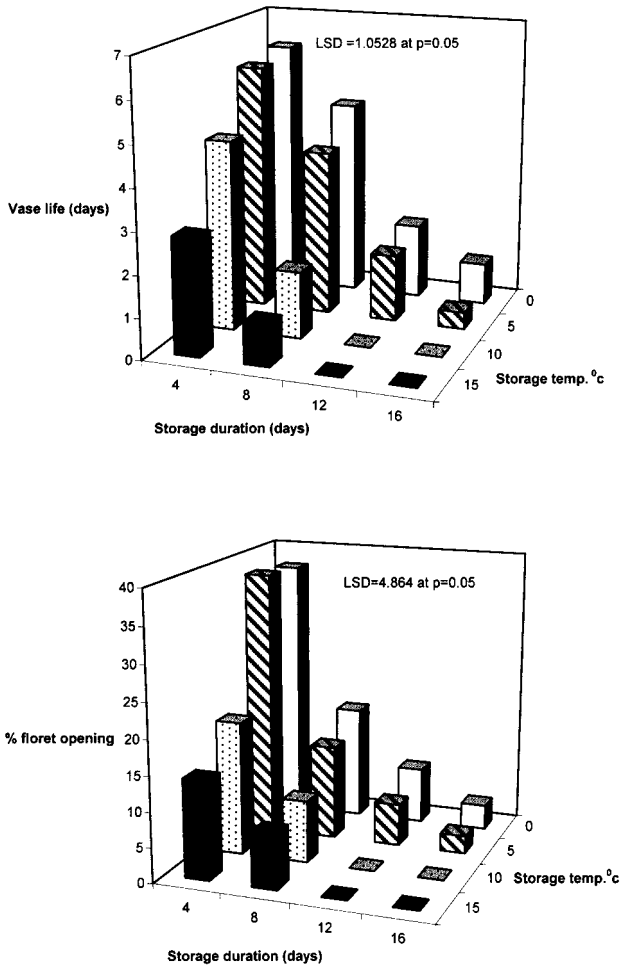

FIG. 1
Effects of storage temperature (°C) and duration (days) on (a) vase life and (b) % floret opening of cut tuberose.

senesced florets exceeded the number of open ones. Fresh weight of spikes was measured every 2 d of the vase period for the various treatments.

Ethylene measurement

Ethylene production by floret buds excised at five developmental stages (young developing floret bud, tight floret bud, swollen floret bud, half open floret and fully open floret) was measured by sealing each floret in a 45 ml vial for 1 h, then determining the amount of ethylene in a 1 ml sample of headspace gas using a photoionization detector (HNU Systems Inc.: Newton, MA, USA) connected to a gas chromatograph (Carle Instruments Inc.: Anaheim, CA, USA). Measurement was done immediately after any treatment on the inflorescences. Single florets per treatment, replicated six times were used in ethylene measurement.

Statistical analysis

Statistical analysis were performed using PC-Excel software package. General linear models two-factor analysis of variance (ANOVA) were fitted. Separation of means was done by Duncan's Multiple Range Test or Student's *t* test at 5% level.

TABLE I
The influence of cold storage methods at 2°C on floret opening and vase life of cut tuberose flowers

Storage (days)	Storage conditions	Floret opening (%)	Vase life (days)
None		44.6 a*	9.3 a
3	Dry	23.3 b	6.8 b
3	Wet	21.3 b	6.2 bc
6	Dry	14.4 bc	6.2 bc
6	Wet	10.1 c	5.2 c

*Means with the same letter are not significantly different according to Duncan's Multiple Range Test, 5% level.

RESULTS

Effects of cold storage

Vase life and floret opening of cut tuberose spikes were markedly decreased by cold storage. The best storage temperature of cut tuberose inflorescences was 0°C to 5°C (Figure 1a and b). Vase life after storage was reduced by increasing time in storage, and at temperatures higher than 5°C (Figure 1a). Floret opening was even more strongly affected by increasing storage period (Figure 1b). Three days of cold storage at 2°C halved floret opening, and reduced the overall vase life by 30% (Table I). In most cold-stored spikes, tight or developing floret buds abscinded by the end of vase life and the upper part of the inflorescence stem often collapsed. Flower buds that were nearly open at the start of storage often opened only partially – one whorl of petals would expand while the rest remained closed. The vase life and floret opening of spikes stored "wet" (with their bases in preservative) was no different from that of spikes stored "dry" (wrapped in newsprint and polyethylene to reduce water loss) (Table I).

Effects of chemical pretreatments on fresh and cold-stored flowers

Holding freshly cut tuberose spikes in a vase solution containing sucrose increased floret opening and vase life by over 30% (Table II). Pulse pretreatment with 20% sucrose further increased substantially the vase life, but not floret opening of spikes placed in preservative solution. Prestorage pulsing of cut spikes with 20% surose largely overcame the negative effect of 6 day's-cold storage (Table II). The vase life of sucrose-pulsed flowers was double that of cold-stored controls, and floret opening was more than double. Quality of the pulsed and stored flowers was indistinguishable from that of non-stored controls pulsed with sucrose, then held in a vase preservative containing sucrose. Even though they did not open, sucrose pulsing also inhibited

TABLE II
The influence of dry storage at 2°C and chemical pretreatments on the keeping quality of cut tuberose flowers

Pretreatment	Dry storage (days at 2°C)	Vase solution	Open florets (%)	Vase life (days)
None	0	HQC 250 ppm	34.3 b*	5.7 c
None	0	HQC +2% sucr.	50.5 a	8.8 b
None	6	HQC +2% sucr.	19.0 c	5.3 c
1 mol STS	0	HQC +2% sucr.	39.5 b	7.8 b
1 mol STS	6	HQC +2% sucr.	33.3 b	5.7 c
20% sucrose	0	HQC +2% sucr.	57.5 a	11.3 a
20% sucrose	6	HQC +2% sucr.	50.1 a	10.5 a

*Means with the same letter are not significantly different according to Duncan's Multiple Range Test, 5% level.

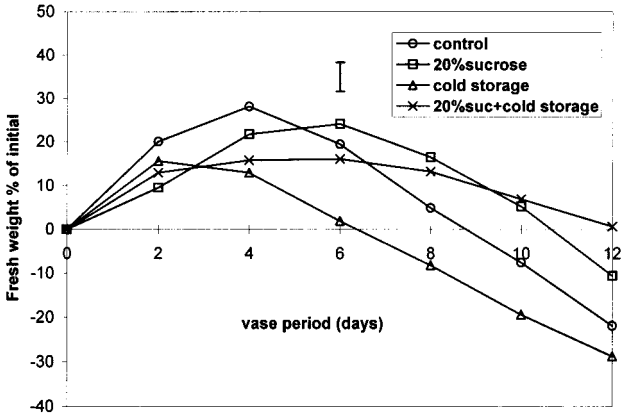

FIG. 2
Effects of cold storage at 2°C and pretreatments (20% sucrose pulse; 20% sucrose pulse plus cold storage) on fresh weight changes in cut tuberose. Vertical bar represents differences between means using LSD ($P = 0.05$).

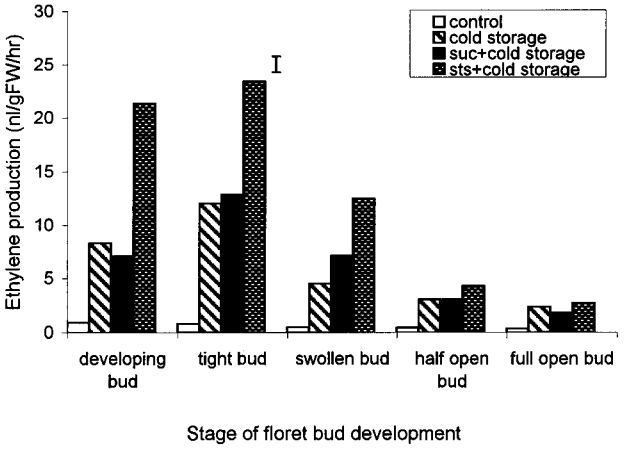

FIG. 3
Effects of cold storage at 2°C and pretreatments (20% sucrose pulse plus cold storage, 1 mM STS pulse plus cold storage) on ethylene production by floret buds of cut tuberose at five development stages. Vertical bar represents differences between means using LSD ($P = 0.05$).

premature abscission of young floret buds. STS pretreatment on freshly cut spikes had a deleterious effect on floret opening (from 50.5 to 39.5%) with no beneficial effect on vase life (8.8 against 7.8 d). Similarly, STS pretreatment on cold-stored spikes significantly decreased their vase life (from 8.8 to 5.7 d) and floret opening (from 50.5 to 33.3%), but there was no significant difference in floret opening between fresh and cold-stored spikes pretreated with STS (Table II).

Changes in fresh weight

The fresh weight of cut tuberose inflorescences increased substantially during the first 2 d in the vase (Figure 2), whether they were freshly cut, or had been cold stored for 6 d. Thereafter, cold-stored spikes which had not been pre-treated with sucrose lost weight rapidly, and had returned to their initial weight after 6 d of the vase period. The maximum increase in fresh weight of fresh-cut spikes was more than double that of stored inflorescences. Pulse pretreatments with 20% sucrose increased the time to maximum weight, and extended the period during which spikes exceeded their initial fresh weight. The vase life of spikes, determined by the time at which there were more senescent florets than open florets, corresponded closely with the time taken to return to their initial fresh weight.

Cold storage and ethylene production

Ethylene production by individual florets was found to be strongly promoted by cold storage (Figure 3). Greatest ethylene production before and after storage was by immature and tight floret buds. Storage increased ethylene production by tight floret buds more than tenfold. Ethylene production by florets from spikes that had been pretreated with 20% sucrose prior to storage was not significantly different from that of non-pulsed cold-stored florets (Figure 3). In contrast, ethylene production by florets from stored stems pre-treated with STS prior to storage was almost double that of the stored controls.

Floret opening was strongly inhibited in freshly-harvested tuberose inflorescences placed in vase preservative in an atmosphere containing 4.5 ppm ethylene (Table III). Pulse application of STS did not increase vase life or floret opening, but did overcome the deleterious effects of exogenous ethylene.

TABLE III
Effect of ethylene (4.5 ppm) and STS (1 μmol) on vase life and floret opening of freshly harvested cut tuberose flowers

Treatment	Vase life (days)	Floret opening (%)
Air	7.2 a*	37.5 a
Air + STS	6.2 ab	33.5 ab
C_2H_4	4.2 c	11.7 c
C_2H_4 + STS	5.8 b	30.9 b

*Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test, 5% level.

DISCUSSION

This study shows that any method of cold storage of cut tuberose inflorescences decreased their vase life and floret opening significantly, even when the spikes were stored wet in a solution containing 2% sucrose (control vase solution). Wet storage for the longer period (6 d) was even more detrimental, especially on floret opening. It is therefore the storage itself, not desiccation during storage that results in poor post-storage performance of the flowers. The hypothesis that the detrimental effect of cold storage might be due to chilling injury of these subtropical flowers was not sustained. Storage was best at the lowest non-freezing temperatures tested (Figure 1a,b).

Mor (1989) similarly found that rose flowers with lower rather than higher water content during storage performed better after storage (dry compared with wet-handled flowers) thereby recommending dry over wet storage. Because of the loss of petal dry weight after cold storage, Mor (1989) suggested that wet-stored rose flowers had higher respiration rates than the dry-stored flowers, which resulted in poor performance after cold storage. The effects of cold storage methods on flower keeping quality differ widely among flower species and their cultivars as demonstrated by Rudnicki *et al.* (1989) who recommended wet storage for carnations.

The pre-storage pulsing of flowers with chemical preservatives such as sucrose and STS has been shown to improve the keeping quality of carnations (Gozczynska and Rudnicki, 1982; Rudnicki *et al*., 1989), roses (Mor, 1989; Serrano *et al*., 1992), *Leucadendron* 'Silvan Red' (Jones, 1991) and *Strelitzia (Halevy et al*., 1978) after cold storage. Pre-storage pulsing of cut tuberose spikes with 20% sucrose significantly improved the vase life and floret opening of cold-stored flowers by maintaining a positive water balance during cold storage thereby indicating greater solution uptake and retention after storage due to greater osmotic potential in flower stems and petals as reported by Halevy (1976). Prestorage pulsing of cut flowers with sucrose has been reported to improve the flower keeping quality after cold storage by maintaining the cell membrane integrity and reducing their sensitivity to ethylene during cold storage (Halevy and Mayak, 1979).

Young flower buds from cold-stored spikes had the highest rates of ethylene production which may have induced their early abscission when spikes were returned to the postharvest evaluation laboratory. Cold storage has been reported to promote ethylene production by rose flower buds (Mor, 1989; Faragher *et al*., 1986). Rudnicki *et al*. (1991) found that excessive accumulation of ethylene in cold storage resulted in subsequent accelerated wilting and senescence of flowers. If young tuberose flower buds have less carbohydrate reserves as we have observed in gladiolus (Waithaka *et al.,* 2001), they probably become sensitive to the ethylene which they produce due to cold storage and therefore, they abscind very early when flowers are returned to the postharvest evaluation larboratory at 20°C. Therefore, pre-treatment of cut tuberose with adequate sugar may protect cold-stored spikes from desiccation and sensitivity to ethylene.

Ethylene inhibitors such as AOA (aminooxyacetic acid) and STS (silver thiosulfate) have been used to extend flower longevity, delay abscission and improve flower keeping quality (Broun and Mayak, 1981; Veen, 1983). STS did not, however, delay senescence of cold-stored and fresh cut tuberose spikes and also depressed their solution uptake. Similar results were reported by Naidu and Reid (1989), who observed a severe reduction in solution uptake by tuberose flower stems pulsed with STS which resulted in rapid senescence of florets. In the current study, the negative effects of STS on tuberose spikes were perhaps not as dramatic as that reported by Naidu and Reid (1989) because all vase solutions used contained 2% sucrose which delays florets abscission and senescence in tuberose. In contrast, STS was reported to delay senescence of cold-stored roses (Mor, 1989), carnations (Rudnicki *et al*., 1989) and *Strelitzia* (Halevy *et al*., 1989).

Flower, bud or leaf abscission can be induced artificiallly by the use of growth regulators or by subjecting the plants or cut flowers to stress conditions such as low or high temperatures or drought (Moe and Smith-Eriksen, 1986; Abeles, 1973; Cameron and Reid, 1983; and Mayak and Halevy, 1971). This abscission can occur before the natural senescence of the plant part. The stress condition is known to promote the biosynthesis of endogenous ethylene which promotes abscission and senescence in some flower species as reported by Borochov *et al*. (1982) and Spikman (1986) on carnations and freesia, respectively. Van Meeteren and DeProft (1982) reported an inhibition of flower bud abscission and ethylene evolution by light and silver thiosulfate in *Lilium*. We observed that exogenous ethylene at 4.5 ppm promoted complete abscission of all open and closed flower buds of tuberose inflorescences by the fourth day of their vase life. This abscission was substantially inhibited by STS but STS did not delay flower senescence as reported in roses and carnations. Ethylene, therefore, may not be important in flower senescence of tuberose, but may promote floret abscission as shown in this study.

The mechanism of the beneficial effect of a sucrose pulse on the performance of cold-stored tuberose flowers remains to be determined. However, the practical implications of our findings are considerable. Therefore harvesting of tuberose spikes with 2 or 3 open florets, pre-storage pulsing with 20% sucrose and dry cold storage at 0°C would markedly reduce the adverse effects of cold storage on vase life and floret opening.

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