

Temperature and Ethylene Effects on Cut Flowers of Carnation (*Dianthus carophyllus* L.)¹

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Abstract. Cut carnation flowers shipped from California by air occasionally arrive at eastern markets in a senescent condition with losses greater in the warm autumn months. CO₂ and C₂H₄ production by the flowers has a pattern similar to that of climacteric-class fruits, with senescence correlated with a rise in release of the gases.

Cut carnation flowers show an enormous increase in respiratory heat with increasing temperature: 89 BTU/ton/hour at 0°C versus 14,718 at 50°C. In C₂H₄-free air, the flowers tolerate elevated temperatures but their vase life is reduced. Their sensitivity to C₂H₄ increases dramatically with increasing temperature, with the threshold concentration partially depending on prior stresses on the flowers.

Flowers in containers exposed to direct sunlight developed temperatures as high as 49.5°C. Air temperatures inside containers shipped via jet aircraft were as high as 35°C. The C₂H₄ concentrations in the containers may reach 10.5 ppm.

The remarkable resistance of cut carnation flowers to mechanical injury, combined with their low metabolic rates at low temperatures, makes refrigerated surface shipments feasible and perhaps economically desirable. Their resistance to injury seems related to their light weight, the damping action of the petals, and the lack of phenolase or readily oxidizable phenolic compounds in the petals.

Open California carnation flowers are currently cut, packed in corrugated paperboard containers, and shipped great distances by air without cooling. Delays between cutting and packing may be for several hr at 12-20°C. During such delays the flowers may be held dry in boxes or with stems immersed in water, with flower temp equal to or slightly higher than the temp of the ambient air.

Packing consists of first lining the container with a sheet of soft paper, then hand placement of layers of 25-flower bunches with one-half of the inflorescences oriented toward each end of the box. This close packing minimizes the distance for heat exchange between the container-ambient air interface and the flowers. Layers of newspapers are often placed between the layers of bunches. When the container is filled, an insulating layer of liner paper is folded across to cover the flowers. Finally, the bunches are secured with a strip of wood inserted laterally across the middle of the container, forced downward against the stems, and stapled into place. The lids, partially or completely telescoping, are secured with tape or twine.

The containers are hauled by unrefrigerated van to the airport. Before being loaded onto the plane they are sometimes left in open sunlight or held in shaded (but warm) environments. Delivery at distant markets is within 18-24 hr of harvest. Off-loading from the plane may be followed, again, by exposure to open sunlight or warm, shaded conditions.

During holiday periods, growers may store flowers for several days at 0-5°C before they are packed and shipped. In most operations the time required to grade, sort, and pack permits the cooled flowers to warm to ambient temp by the time the containers are closed.

Wholesalers or retailers occasionally report that the carnations arrive appearing "cooked," "asleep," or "sleepy," or having an unacceptably brief display or vase life. These reports are most frequent when the weather is warm in the areas where

the flowers are grown. The deterioration in the brief transit period is so great that the stress placed on the flowers during shipment must have been severe.

Carnation flowers produce ethylene (C₂H₄) as they senesce (14) and are sensitive to low concn of the gas at room temp (2, 10, 15, 17). The precise concn-temp-time relationships in C₂H₄-induced senescence of these flowers have not been elucidated, but Barden and Hanan (2) and Ueta (17) have presented data indicating that the adverse effect is profound even at modestly elevated concn and temp.

Information on the respiratory rates of carnation flowers at various temp is too scant to permit reliable computation of rates of release of respiratory heat. Lutz and Hardenburg (12) estimated the storage periods for various flower species but offered no information on their metabolic activity. Such data are essential for evaluating flower performance under commercial conditions and are critical to studies of cooling and packaging requirements.

Information is inadequate on the temp attained by carnation flowers in air transit. In 1962 Harvey et al. (9) reported a maximum temp of 16°C (61°F) in a 22-hr transit period from Encinitas, CA., to Washington, D.C. Currently, many flowers are shipped via jet airliners in pressurized, heated cargo compartments.

We sought information that might explain the occasional loss in quality of carnations during transit. The specific objectives were to determine:

- 1) Rate of respiration and respiratory heat production at 0-50°C.
- 2) Warming rates and temp attained in containers exposed to direct sunlight and to warm, shaded environments.
- 3) Temperatures attained in commercial containers during transcontinental air shipments.
- 4) Ethylene concentrations in packed cartons under simulated shipments.
- 5) Influence of a range of temp and C₂H₄ concn on flower quality and vase life.
- 6) Influence of cool-storage and storage conditions on flower quality and vase life.
- 7) Influence of prior stress on flower sensitivity to C₂H₄.

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⁴Murr, D. P. 1973. Influence of temperature, storage atmosphere, and chemical treatment on maturation and o-diphenol oxidase activity of cultivated mushrooms (*Agaricus bisporus*) after harvest. Ph.D. dissertation, Univ. Calif., Davis. 149 p.

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Materials and Methods

Improved White Sim' and 'Scania' were obtained on the day harvest at Watsonville, CA., and transported within 3 hours to Davis in an air-conditioned station wagon. The flowers were commercially open and of top quality.

Respiratory rates were measured by the method of Claypool and Keefe (5), and these data were used for computing respiratory heat production by the method of Lutz and Ardenburg (12). Rates of C_2H_4 production were measured by the method of Maxie et al. (13), and the identity of the gas was confirmed by the method of Burg (4). Aeration of the flowers was continuous at a rate precluding CO_2 concn in excess of 5% around the flowers.

Ethylene treatments were made by continuous aeration from mixtures of air and C_2H_4 prepared with flowmeters described by Claypool and Keefe (5). Concentrations were periodically verified as described above. Effluent mixtures were passed through cylinders of "Purafil" to remove the C_2H_4 , thereby avoiding cross contamination among treatments. Readings taken in the air in the room confirmed the efficiency of the removal.

Samples of the air inside packed containers were withdrawn for C_2H_4 analyses by a gas-tight syringe fitted with a 2 1/2-inch hypodermic needle. The needle was inserted into the container and a 5-ml sample withdrawn. Two successive samples were used to purge the syringe and needle, and then 2 ml of the third sample were analyzed as described above.

Flower temp were measured by inserting copper-constantan thermocouples into the ovary of individual flowers. A 24-point Minneapolis-Honeywell recording potentiometer was used to record temp. Air temp inside packed containers during air treatment were measured by placing freshly calibrated Ryan recording thermographs among the flowers as the containers were packed.

Storage tests were conducted at 0-5°C with flowers under 3 conditions: dry in commercial containers; freshly cut stems

immersed in distilled water; and similarly prepared stems in tap water. All flowers were rapidly cooled to the storage temp before being packed or placed in water. The initial temp of the water was approximately 25°C and the jars were freshly washed before the storage tests.

Simulated surface transport was conducted by methods of Guillou et al. (7). Flowers were subjected to vibration at forces of 1.1 and 3.6 G at 0 and 20°C for as long as 180 and 30 min, respectively.

Acetone powders for phenolase assays were prepared from petals by the method of Murr⁴. Extracts for phenols were made by the method of Creasy et al. (6), and tests for enzymatic browning of the extracts were conducted with mushroom phenolase provided by Murr⁴.

Vase life in all studies was determined by cutting stems to 50.8 cm (20 in.), placing the cut ends in 2 l distilled water, and displaying at 20°C under continuous light at 190-250 ft-c. Senescent flowers were counted and discarded daily.

Results

A typical pattern is shown in Fig. 1 of respiratory drift and C_2H_4 production at 20°C of a sample selected from among the samples collected each month for a year from 6 climatic areas in the Watsonville-Salinas district. The respiratory drift was similar to that of ripening fruits exhibiting a climacteric (3); an initial decline; onset of increased C_2H_4 production; a rapid rise to a peak in production of both CO_2 and C_2H_4 ; and a second decline. Senescent collapse began shortly after the beginning of the increased respiratory rate.

Table 1. Respiratory rate, heat, and temp coefficients (Q_{10}) for 'Improved White Sim' carnation flowers at 0-50°C.

Temp	Respiratory rate mg/ CO_2 /Kg/hr	BTU/ton/hr	Q_{10}^2
0	9.7	89	--
10	30.0	275	3.1
20	239.0	2,191	8.0
30	516.0	4,730	2.2
40	1,053.0	9,653	2.0
50	1,606.0	14,718	1.5

$$^4\text{Ratio} = \frac{\text{respiratory rate at } T^{\circ} + 10^{\circ}}{\text{respiratory rate at } T^{\circ}}$$

Flowers held for 6 hr at 10°C increments in the range 0-50°C show an enormous increase in respiratory rate and heat production (Table 1). The increment was greatest between 10 and 20°C, where the temp coefficient (Q_{10}) was 8.

In C_2H_4 -free air, vase life is substantially reduced as temp increased (Fig. 2), but even at 40°C the carnations would be marketable if exposure did not exceed 4 hr. Even though severely wilted following exposure to elevated temp, flowers recovered when placed in distilled water at 20°C. Since the "sleepy" condition was not induced in simulated transit by elevated temp alone, the effect of C_2H_4 at various concn and temp was examined. Concentrations in ppm were: 0, 0.05, 0.12,

Table 2. Concentrations of C_2H_4 and time of exposure resulting in unacceptable reduction of vase life of 'Improved White Sim' carnations at various temp.

Temp, °C	Exposure time	C_2H_4 ppm
0	3 days	22.0
0	4 days	2.60
5	2 days	0.9
5	4 days	0.12
20	6 hr	2.78
20	18 hr	0.96
30	12 hr	0.37
40	5 hr	0.37

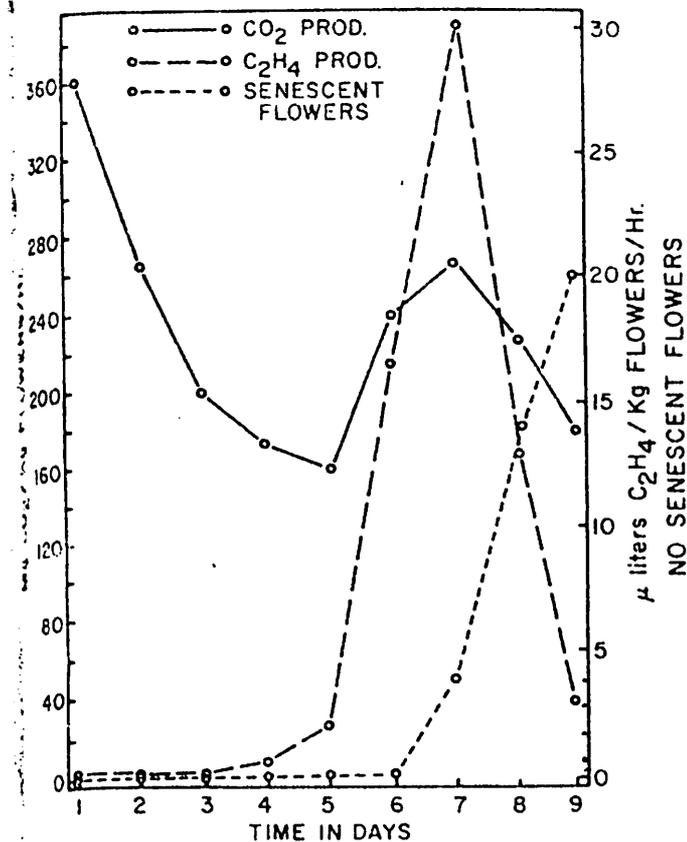


Fig. 1. Rates of respiration, ethylene production, and senescence of flowers of 'Improved White Sim' carnation at 20°C.

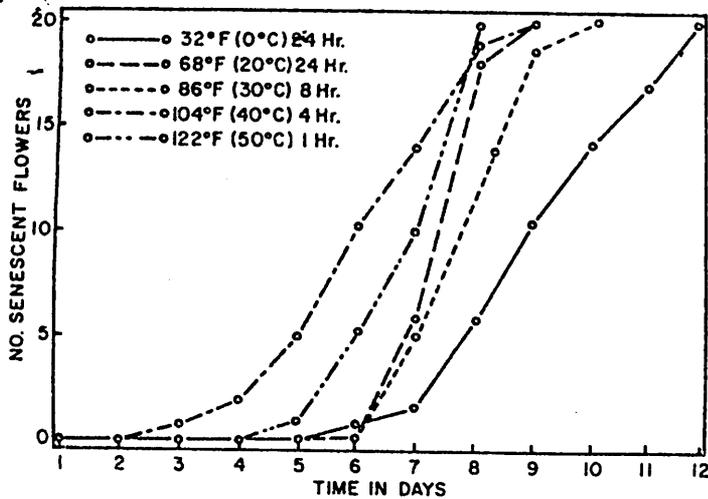


Fig. 2. Effect of temp on vase life of flowers of 'Improved White Sim' carnations exposed in ethylene-free air.

0.37, 0.96, 1.06, 2.78, 4.31, 8.41, and 22.0. Temperatures were 0, 5, 20, 30, and 40°C. As expected, concn, time of exposure, and temp all influenced senescence rate. Table 2 shows the concn and time of exposure resulting in an unacceptable reduction in vase life of the 'Improved White Sim' cultivar at various temp. When first placed in distilled water at 20°C flowers exposed to injurious concn would partially expand and become turgid. If concn and time of exposure were less than those given in Table 2, but greater than 0.05 ppm, the flowers would regain turgor but senesce prematurely, with the rate depending on concn (Fig. 3). Flowers partially recovered if held for 1 day at 20°C following a 5-hr exposure to 40°C and 1.06 ppm C₂H₄ or more. After an additional day, all flowers exposed to 2.70 ppm had senesced while some of those exposed to 1.06 ppm were turgid and the rest wilted. At a given temp, the length of the period of partial turgidity is concn-time-related. The transition state lasted only a few hr at low concn (0.05 ppm at 40°C) but required approximately 30 hr with exposure to 1.06 ppm.

Elevated temp seems to sensitize carnation flowers to C₂H₄. Flowers treated overnight at 20°C with 120 ppb after exposure for 6 hr to 40°C senesced immediately while samples held at 0°C were unaffected.

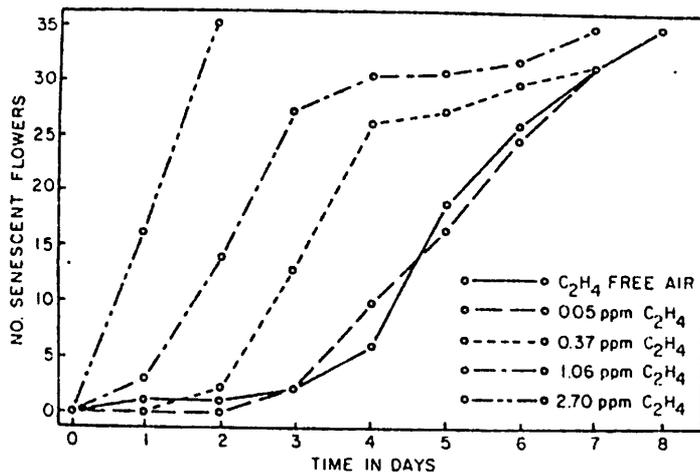


Fig. 3. Effect of 5-hr exposure at 40°C to various concn of ethylene on rate of senescence of flowers 'Improved White Sim' carnations. Data are averages from triplicate samples of 36 flowers each.

Exposing carnation flowers to 40-50°C may seem extreme until one considers that the containers are often exposed to

direct sunlight in transit. The rate of warming for flowers cooled to 5°C and then (with thermocouples inserted into the ovaries of selected specimens) repacked, and the container exposed to direct sunlight for 4 hr when the ambient shade temp ranged from 20-28°C is shown in Fig. 4. Flowers in the top and bottom layers of the container warmed to 49.5 and 27°C, respectively. In containers similarly prepared and held in shade at 28°C flowers in the top and bottom layers warmed to 24 and 18°C respectively (data not shown).

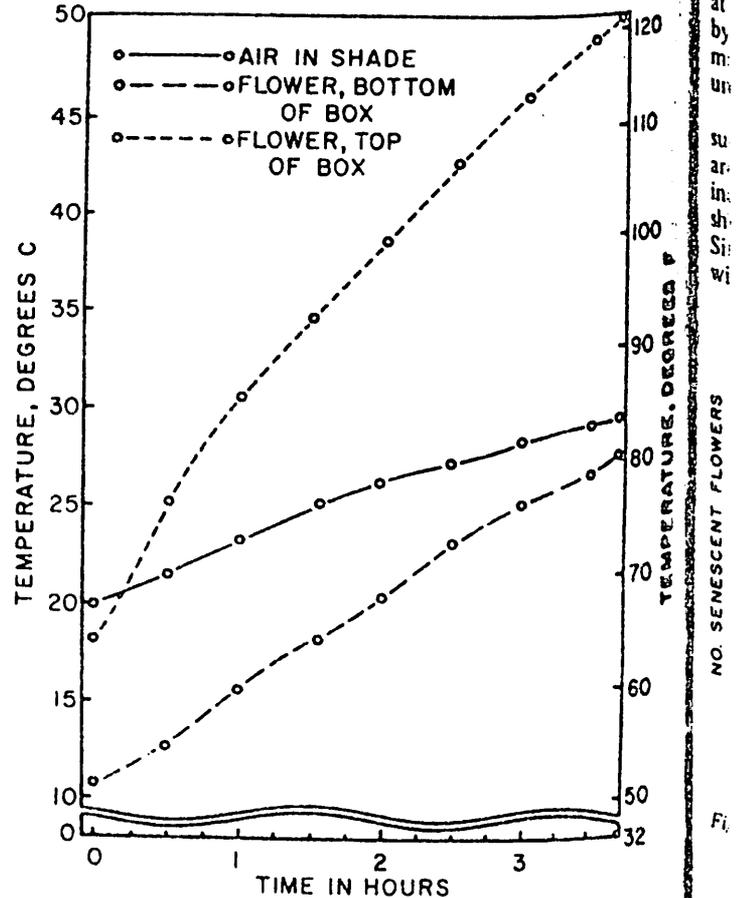


Fig. 4. Effect on flower temp of 4-hr exposure to direct sunlight of a packed container of 'Improved White Sim' carnations.

Ten test shipments by air were made in August and September, 1972. Air temp inside the containers as recorded by Ryan thermographs increased progressively from the time of

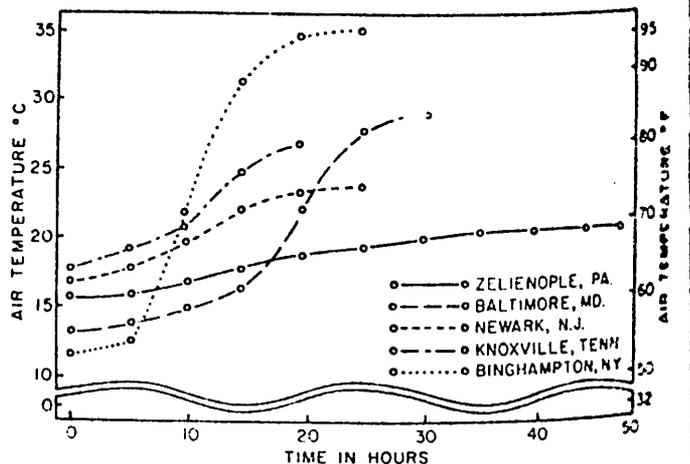


Fig. 5. Air temp inside packed containers of 'Improved White Sim' carnations during transcontinental air shipments.

Testing. Data for 5 of the tests are shown in Fig. 5. The highest temp recorded in any test was 35°C, but all were in the range where the flowers would be highly sensitive to C₂H₄. Considering the respiratory heat production of carnations at elevated temp (Table 1), the flowers may have been somewhat warmer than the air in the carton.

The concn of C₂H₄ inside containers of packed carnations varied widely. We have measured concn as low as 9 ppb in containers where the flowers were promptly cooled to 0, and held at, 0°C. Uncooled containers placed at 0°C for a week followed by 24 hr at 20°C, had a concn of 10.5 ppm. This becomes a major consideration in the interpretation of flower behavior under commercial conditions.

Both 'Improved White Sim' and 'Scania' can be stored successfully at 0°C for 2 weeks if cooled promptly. Typical data are shown in Fig. 6. Benefits from the use of water were inadequate to justify the costs and storage space involved. It should be noted that after 2 weeks storage the 'Improved White Sim' flowers in these experiments were marginally marketable with respect to vase life.

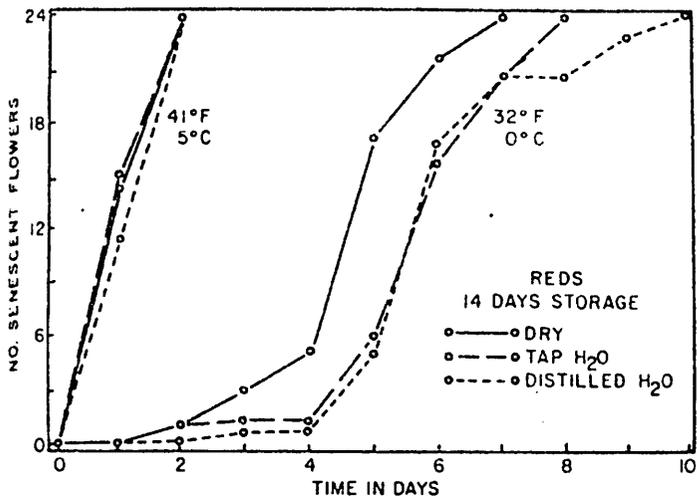


Fig. 6. Effect of 14 days of storage at 0°C and 5°C on vase life of flowers of 'Scania' carnations.

Simulated transit tests showed carnation flowers to be remarkably resistant to vibration injury. Flowers subjected to 1.1 G for 30 min at 20°C and 0°C showed no injury. Increasing the time to 3 hr, or the force to 3.6 G for 30 min, similarly had no adverse effect aside from faint evidence of dehydration at petal edges of 'Scania'. Vibration had no measurable effect on C₂H₄ production or vase life.

No measurable phenolase activity was found in acetone powders prepared from carnation petals. Mushroom phenolase gave no reaction when placed in extracts of the phenols from the petals even though the enzyme was shown to be highly active with catechol as a substrate.

Discussion

We recognize that the use of amendments such as sugar, hydroxyquinoline, and silver nitrate (1, 11) in the vase water could have extended the vase life of the flowers. That would have been an added complexity, however, and it is improbable that they would have counteracted the stresses imposed by elevated temp and C₂H₄.

The role of C₂H₄ in inducing senescence of carnations is not known. The production rate of the gas increases just prior to the onset of senescent collapse of the flowers. The respiratory rate increases immediately after the increase in C₂H₄ production in a manner similar to the onset of ripening in the climacteric class of fruit (3). This confirms the work of Nichols (14), although he used individual flowers enclosed in an air-tight system. This

might have exposed the flowers to a senescence-inducing concn of C₂H₄ earlier than occurred in our continuously aerated system.

In samples taken monthly for a year from 6 growers in the Salinas-Watsonville area, no differences in rate of C₂H₄ production were found in the presenescent phase. Differences in vase life varied among the various samples and occasionally from month to month, but were always correlated with the surge in C₂H₄ production described above.

Carnation flowers have a high requirement for sugar, and C₂H₄ increases respiratory rate substantially. It is questionable, however, that depletion of substrate is the underlying cause for collapse of the petals. Under certain conditions the vascular bundles of the stems of carnations become plugged by microbial action (1), leading to wilt of the flowers. In short-term exposure to high concn of C₂H₄, collapse is probably not microbial but rather an endogenous phenomenon.

It seems futile to seek a precise "threshold" concn of C₂H₄ for injury to carnation flowers, for it would depend on the previous stresses on the flowers. Those subjected to high temp, long-term storage, or low concn of C₂H₄ can be expected to be much more sensitive to the gas than are flowers grown under good conditions, cooled promptly, and kept cool. Hall (8) and Uota (16) made similar observations. We do not know the nature of the increased sensitivity to C₂H₄ of stressed flowers. It may be a direct action of the gas or a stimulation of increased C₂H₄ production by the flowers, which would, in turn, appear as an increased sensitivity.

Our data seem to explain why air-shipped carnations occasionally show symptoms of undue stress upon delivery. Temperatures in route may be considerably higher than reported by Harvey et al. (9). Even so, the flowers may survive and be marketable if levels of C₂H₄ during transit are not injurious. Clearly, containers should never be placed in open sun or in warm rooms. Preferably, the flowers should be cooled to 0°C and kept there throughout transit. The flowers should not be placed in confined space with ripening fruit or where engines fueled by gasoline or kerosene are operating.

Flowers exposed to high concn of C₂H₄ at low temp may also be marketable. The major losses will occur where high temp and exposure to C₂H₄ are combined.

Temp during storage is also critical to cut flowers. Flowers stored at 0 and 5°C differ in storage life by 5-7 days. We consider 4-5 days at 5°C as the maximum time that would allow marketable flowers. Even that time would give a shorter vase life than that of flowers held continuously at 0°C. Similarly, stored flowers would likely show increased sensitivity to C₂H₄.

Three facts contribute to the remarkable tolerance of carnation flowers to vibration injury: 1) the light wt of an individual flower, reducing the impact force of the drop; 2) the damping effect of the petals, which acts as springs to cushion the flower; and 3) the lack of phenolase and readily oxidizable phenols in the petals. We estimate that these flowers are 6-8 times as resistant to vibration injury as are 'Bartlett' pear fruits.

Considering the insulating effect of the paper materials currently included in carnation containers and the tolerance of the flowers to mechanical injury, we believe 2 steps need immediate implementation: 1) removal of insulating materials; and 2) development of a system for shipping the flowers by refrigerated surface vehicles. Cut carnation flowers seem to tolerate moderate temp without injury. This offers the possibility of employing vented containers and forced-air cooling as protective procedures. The use of surface carriers would mean a major change in marketing procedures for cut carnations, but the potential benefits in flower quality and in reduced packaging, handling, and shipping costs deserve serious consideration.

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Sorting Blueberries for Quality by Vibration¹

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Abstract. A method is described and test results reported for sorting blueberries with low-frequency vibration. Separation was dependent on fruit firmness which is affected by roughness of handling and other softening factors.

Firmness, as measured by compressing blueberries 0.2 cm between flat plates, statistically explained 58 to 72% of the variation in frequency for removal of berries from a vibrating trough with constant energy input. When comparing ripeness with frequency for sorting, light transmittance (ΔOD ; 740-800 nm) values, which indicate anthocyanin pigment concentration, explained only 10% of the variation in sorting frequency.

Berries of several cultivars and harvest dates were vibration sorted and tested for susceptibility to decay. Sorting frequency statistically explained 75% of the variation in decay level. Thus, the vibration method should be suitable for sorting blueberries into groups of different shelf life.

High-bush cultivars are the major source of blueberries sold fresh in the United States. Considerable labor is required to harvest by hand. As a result in recent years there has been a trend toward harvesting with large over-the-row machines. Mechanical harvesting, however, subjects berries to impact forces which soften them and increase losses from decay (1, 3). Improved harvester design should minimize softening, but some means of removing damaged and soft fruit is needed. A sorting system should separate fruit with a short shelf life from those with a long shelf life. Fruit predicted to have short shelf life could be frozen and processed into a high quality product.

Because overripe fruit deteriorates rapidly, one approach to sorting blueberries is on the basis of ripeness (6). There is good correlation between ripeness and the difference in light transmittance (ΔOD) through blueberries at wavelengths of 740 nm and 800 nm, respectively (2, 4). Thus, a light-transmittance difference sorter might be commercially feasible if design details can be worked out. However, it would not remove fruits too bruised (soft) to go to market. Correlation between blueberry ripeness and firmness are low (3), in contrast to fruits such as muscadine grapes (5). Thus, a method for sorting blueberry

fruits too soft as well as too ripe is needed because softness reflects bruising but not ripeness.

As a blueberry becomes soft and more viscous, its natural resonant frequency, considered as a spring-mass system responding to external forcing, decreases and the berry absorbs more energy internally as heat rather than being put into motion (7). Restating this, the general response of the berry to external sinusoidal forcing decreases as the berry becomes more viscous and less elastic. More of the vibration energy is dissipated as internal heat rather than being stored in the berry and then released by forcing the berry away from the contacting vibrating surface. Thus, theoretically it should be possible to use either of 2 characteristics as a basis for sorting. The first is that the resonant frequency of softer berries will be lower and the second is that at any nonresonant frequency more viscous berries will be less responsive to applied vibrational forcing.

The object of this research was to evaluate a sorting method whereby blueberries are subjected to low-frequency vibrational energy and allowed to react by bounding away from the source

Methods

A variable frequency and stroke electrodynamic vibrator was used to provide the desired vibratory motion (Fig. 1). A 90-degree V-shaped trough was mounted on the vibrator so that the trough was vibrated perpendicular to its length in a direction parallel to one side. This side was 1/2 inch wide and positioned 30 degrees from the horizontal. The side of the trough nearest the vibrator transmitted vibratory force to the berries so that they could respond by bounding away and over

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