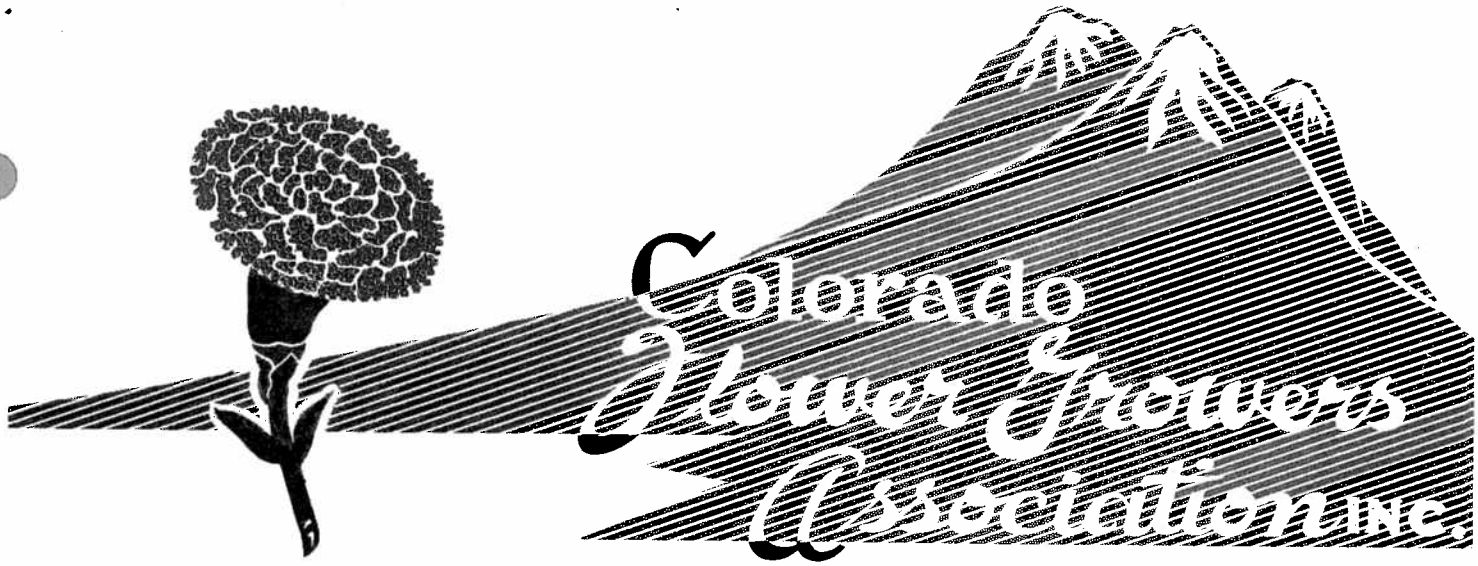

IN COOPERATION WITH COLORADO STATE UNIVERSITY
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Controlled Atmosphere (CA) Storage of Carnations

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The possible benefits of CA storage for carnations do not appear to warrant installation expense. In 2 years of research, carnations have been stored under a variety of conditions from 3 days to 9 weeks. With proper handling, flowers can be kept up to 5 weeks in conventional 33°F storage without noticeable decrease in keeping life. CO_2 concentrations above 4% are dangerous. Oxygen concentrations above 1.0% have no effect. Below 0.4% O_2, depending upon storage temperature, flowers may ferment.

Modifying the atmosphere around horticultural products in storage has been studied for several years. With some commodities, particularly apples, it is commercial practice to reduce oxygen and increase CO_2 concentrations in order to prolong storage life without reducing marketability. The exact concentrations of O_2 and CO_2, proper temperatures, handling, etc., depend upon the variety and its previous history (that is; how it was grown and season in which grown). Usually, the necessary conditions for proper storage have been found empirically. There do not appear to be any general principles by which optimum storage conditions for a commodity can be predicted.

Methods and Materials

General --Except where noted, storage trials beginning April, 1964, were conducted in coolers controlled at various temperatures to within ±1°F. Carnation varieties were Scania and Red Gayety, the majority buds showing 1/2 inch color (1). With one exception, all checks and flowers removed from storage were subjected to pre-conditioning by re-cutting the stems, placing in warm Cornell solution[1], and holding at 33° for 24 hours. The flowers were then placed in fresh, warm CS solution and put in keeping rooms maintained at 75°F, ± 1-1/2°. Keeping on buds was started from the day when the majority of flowers in a treatment had opened to where the outer petals were almost horizontal. The flower was considered past when there was obvious wilting, blackening or curling of the petals. One day was subtracted to obtain keeping life. Additional tap water was added to maintain sufficient fluid in the containers.

Various concentrations of O_2 and CO_2 were obtained by mixing air, CO_2 and N_2 on flow mixing boards, usually located in constant temperature rooms. Flow rates were approximately 100 ml/min. The tanks were not purged, and generally required 48 to 72 hours to reach the desired levels. A Hayes-Orsat apparatus was used to analyze for O_2 and CO_2, except where the O_2 concentration was less than 1.0%. For low O_2 levels, a modified platinum electrode was employed. Nitrogen tanks were found to vary in O_2 content. These were checked, and tanks with concentrations greater than 0.1% (1000 ppm) were rejected. As the result of variations in nitrogen purity, temperature changes, atmospheric pressure changes, etc., it was not possible to maintain O_2 levels consistently. Concentrations occasionally varied more than 0.2%.

Initially, 30 gallon drums, with double layer polyethylene covers, were employed. Later, the change

[1]Cornell Solution: 200 ppm 8-hydroxyquinoline sulfate, 50 ppm silver acetate, and 5% sugar

was made to instrument cases (about 20 gallons capacity) where the lid could be securely clamped. Air tightness was difficult to achieve, and it was sometimes necessary to reseal lids two or three times.

The larger experiments employed 24 flowers per treatment. Ten was the minimum. Small numbers of flowers were obtained from the CSU research range and all were Red Gayety. All Scania and some Red Gayety were obtained from the Denver flower market. Bunches were cut open and the flowers re-randomized. Precise source of flowers from Denver cannot be verified. Proper wrapping of carnations while in storage was found to be critical. The bleaching shown on Red Gayety in Figure 1, was attributed to rapid drying of the flowers. The exact cause has not been proven. But, the occurrence was reduced by bubbling each gas through water, placing water in the bottom of the storage container, wrapping the flower heads with a layer of paper and wrapping stems and flowers in polyethylene.

Figure 1. Typical severe bleaching on Red Gayety carnation after 3 weeks of storage at 33°F. in a flowing gas mixture. Thought due to insufficient humidity.

Table 1. Outline of experiments in controlled atmosphere storage.

Expt. No.	Date started	Variety	Number per treatment	Buds or Open	Temperature(s)	Concentrations O_2%	Concentrations CO_2%	Duration	Remarks
1	4- -1964	Scania	25	Buds	33°F	(Discarded after 3 weeks due to severe bleaching, flowers not wrapped)			
2	5-15-64	Scania	25	Buds	33	2.0 5.0 2.0 2.0 5.0	 5.0 10.0 5.0	9 weeks	Flowers removed at intervals of 3, 5, 7 and 9 weeks. Comparison in flowing air.
3	10-30-64	Scania	25	Buds	50	9	70	5 days	Plastic bags charged with CO_2 and nitrogen, respectively, and left for 5 days at the indicated temperatures, Comparison in flowing air.
4	11-23-64	Red Gayety	15	Open Buds	50 45 40 33	9	70	10 days	Plastic bags charged with CO_2 and N_2, respectively, and recharged on 5th day. Comparison in flowing air.
5	11-30-64	Red Gayety	10	Buds	50 45 40 33	Flowing nitrogen		3 weeks	Comparison in flowing air.
6	12-30-64	Scania	25	Buds	50 45 40 33	0.6 to 0.8		3 weeks	Comparison in flowing air.
7	2-4-65	Scania Red Gayety	25 10	Buds Open	50 45 40 33	0.4 to 1.0		6 weeks	All treatments terminated at 3 weeks except 33° which was carried to 6 weeks. Comparison in flowing air.
8	3-5-65	Scania Red Gayety	25 15	Buds Open	65 to 75	Flowing and still air		72 hours	Stored with geraniums and mums, compared with flowing air, still air and checks, with and without preconditioning.
9	3-18-65	Red Gayety	10	Buds	33 60	0.4 to 0.7		6 days	Shift to new containers, comparison with flowing air and still air.
10	3-30-65	Red Gayety	10	Buds	33 60	0.5 to 0.9		7 days	Containers sealed with petroleum jelly, comparisons with flowing and still air.
11	4-17-65	Red Gayety	10	Buds	33 60	0.5		10 days	Tanks purged at high flow rates, drawdown 24 hours.
12	11-6-65	Scania Red Gayety	24 24	Buds Buds	33	0.6 0.8 1.0 1.4 19.0 19.0	 6.4 17.1	9 weeks	Scania and Red Gayety removed at 5 weeks, Scania only at 9 weeks. Comparison with flowing air.
13	1-29-66	Scania	24	Buds Open	33 38	0.7 0.7 19.0	 3.8 3.8	9 weeks	Scania buds and open flowers removed at 5 weeks, buds only at 9 weeks. Comparison with flowing air at 33.

Experiments -- Experiments included in this report are outlined in Table 1. Three were of 9 week duration. A number were 3 weeks or less for purposes of testing preconditioning, comparing buds with open flowers, effects of high temperatures, etc. But included are a number of experiments prematurely terminated due to refrigeration failure. The term "flowing air" refers to treatments in which air was constantly passed through the sealed container at 100 ml/min. "Still air" refers to flowers sealed in containers without circulation of any kind.

Table 2. Results of CA storage, Experiment 2, Scania carnations stored as buds at 33°F up to 9 weeks.[1]

Duration (weeks)	Flowing air	O_2 - CO_2 concentration (%) 2-0	2-5	2-10	5-5	5-0	Mean
3	14.0	14.3	14.4	13.1	12.6	14.7	13.8
5	13.3	13.5	13.0	11.4	13.2	13.1	12.9
7	12.5	12.6	13.0	11.9	12.5	12.7	12.5
9	10.3	9.2	10.5	10.8	9.7	9.7	10.0
Mean	12.5	12.4	12.7	11.8	12.0	12.6	12.3

[1]Check discarded.

Table 3. Results of CA storage, Experiment 12, Scania and Red Gayety carnations stored as buds at 33°F up to 9 weeks.[1]

Duration (weeks)	Variety	Flowing air	O_2 - CO_2 concentration (%) 0.6-0	0.8-0	1.0-0	1.4-0	19.0-6.4	19.0-17.1	Mean
5	Scania	10.3	10.0	10.7	12.3[4]	8.8	12.2	---[2]	10.3
5	Red Gayety	12.3	11.6	10.8[4]	13.3	11.9	12.7	---	11.6
9	Scania	7.2[3]	10.8	8.5	9.3	9.5	---	---	9.1
Mean		9.9	10.8	10.0	11.6	10.1	----		10.3

[1]Check keeping life: Red Gayety 8.1 days. Scania 9.6 days.

[2]Flowers discarded due to severe foliage drying. Flowers continued to develop normally. Results not included in the means.

[3]Severe mold development, a number of flowers discarded the first two days.

[4]Red Gayety only in 1.0% O_2, 5 week treatment and Scania only in the 0.8% O_2, 5 week treatment.

Table 4. Results of CA storage, Experiment 13, Scania carnations stored as buds and open flowers at 33 and 38° F up to 9 weeks.

Duration (weeks)	Open or buds	33° O_2 - CO_2(%) Flowing air	Still air	0.7-0	0.7-3.8	19.0-3.8	38° 0.7-0	0.7-3.8	Mean
5[2]	Open	11.3	10.0	11.0	11.4	9.6	9.2	6.9	10.0
5[2]	Buds	10.4	10.7	9.9	10.1	9.8	9.1	9.2	9.9
9[3]	Buds	9.5	10.1	9.5	9.8	9.2	9.0	8.8	9.4
Mean		10.4	10.3	10.1	10.4	9.5	9.1	8.3	9.7

[1]Check keeping life: Buds -- 13.0 days. Open flowers -- 10.8 days.

[2]HSD, differences required for significance at 1% -- 0.6 days.

[3]HSD, differences required for significance at 1% -- 0.8 days.

Results and Discussion

Nine week trials -- The results of the 3 nine week trials were presented in Tables 2 through 4. For purposes of comparison, significant differences for one statistical analysis are given in Table 4. With the size sample (24), differences of less than 1 day were mathematically significant. This was not realistic. As a practical rule of thumb in all experiments, differences of less than 3 days were usually disregarded. Considering the expense and effort involved in controlling gaseous concentrations at levels less than 1.0%, 4 to 5 days would be a better value.

It appears that: 1) CO_2 concentrations above 4% were definitely harmful. 2) Storage for periods of 9 weeks reduced keeping life although the decrease was usually less than 3 days. 3) Five week storage in flowing air, and occasionally as long as 9 weeks, was good as in any of the gas mixtures. There does not appear to be any real retention or enhancement of keeping life through the use of low oxygen concentrations over long periods.

Figure 2. Damage from high CO_2 (above 6%) concentrations in long-term storage (5 to 9 weeks). Foliage dried and crumbled although flower opened normally. Note incipient bleaching on outer petals.

Figure 3. Freshly cut Red Gayety carnation flower on the left compared with a Scania carnation stored for 5 weeks in flowing air at 33°F. Picture taken 6th day after flower opened.

Figure 4. Comparison of a freshly cut red carnation with various CA treatments. From left to right: Fresh, low O_2, flowing air, high CO_2. Flowers stored as buds for 9 weeks, picture taken the 5th day after opening.

Pictorial comparisons of treatments may be made in Figures 2 through 4. Figure 2 shows damage resulting from high CO_2 atmospheres in long term storage. Surprisingly, flowers continued to develop normally while foliage dried and crumbled. Figure 3 compares a freshly cut flower with one stored 9 weeks and opened for 6 days. Generally, there were no marked differences in flower characteristics between treatments (Fig. 4).

Flowers in Experiments 12 and 13 often broke over, but continued to develop normally. The 8-hydroxyquinoline sulfate concentration in CS solution was cut in half in Experiment 13. Work by Holley (unpublished) indicates that 50 ppm is more suitable. As breakover did not occur at all times of the year, it appears that maximum concentrations of 8-hydroxy in keeping solutions will vary, depending upon the previous history of the cut flower.

Variation in keeping life -- During the investigation, keeping life of check treatments varied as much as 5 days. This variation is shown in Table 5 where check treatments for all experiments have been compared with storage for various periods in flowing air. Where the keeping life was low (Expt. 3, 6, 12), the storage seemed to enhance keeping. In Experiments 5, 8 and 13, however, the flowing air treatments kept less than the checks. The Red Gayety in Experiments 4, 5, 7, and 9 through 11 were obtained at the Research Greenhouses. Flowers for all other experiments came from Denver. It may be noted that CSU flowers consistently kept 10.4 days or longer, whereas life of Denver flowers varied considerably. It is possible that these variations may be attributed to growing conditions, as well as the time of year in which they were grown.

It can be noted (Table 5) that differences in total mean keeping life between checks and flowing air for all experiments was negligible. This tends to firm the conviction that carnation keeping life will not be significantly reduced by 5 weeks of conventional storage. However, several times extreme variation was noted in keeping life of individual flowers in a treatment. Occasionally it exceeded 8 days. This would question the validity of any mean assigned to a treatment. Until such variation is reduced complaints will always be received, particularly where the customer can attribute the poor keeping to the fact that the flowers were stored.

Table 5. Variation in check keeping life, all flowers subjected to preconditioning, compared with treatment in flowing air and duration of experiment.

Experiment	Variety	Buds or Open	Keeping life (check)	Mean of comparison (Flowing air)	Duration of experiment
3	Scania	Buds	7.4	11.5	5 days
6	"	"	9.0	10.5	3 weeks
7	"	"	9.8	10.3	6 weeks
8	"	"	11.5	10.6	72 hours
12	"	"	9.6	10.3	5 weeks
12	"	"	9.6	7.2	9 weeks
13	"	"	13.0	10.4	5 weeks
13	"	"	13.0	9.5	9 weeks
Mean of Scania buds			10.1	9.9	
13	Scania	Open	10.8	11.3	5 weeks
4*	Red Gayety	Buds	10.6	13.4	10 days
5*	"	"	15.6	10.7	3 weeks
9*	"	"	10.4	10.7	6 days
10*	"	"	12.6	11.1	7 days
11*	"	"	11.0	11.0	10 days
12	"	"	8.1	12.3	5 weeks
Mean of Red Gayety buds			11.4	11.5	
7*	Red Gayety	Open	11.5	10.4	3 weeks
8	"	"	11.8	7.0	72 hours[1]
Mean of Red Gayety			11.6	8.7	
Mean			10.8	10.4	

[1]72 hours at 65 to 75°F, all others stored at 33°.
*Flowers from CSU Research Range, all others from Denver market.

Table 6. Results of Experiment 8. Scania buds and Red Gayety open flowers stored under varying conditions for 72 hours at 65 to 70°F.

Condition	Buds Scania	Open Red Gayety	Mean
Check (without preconditioning)	9.2	8.9	9.1
Check (with preconditioning)	11.5	11.8	11.6
Stored with geraniums	10.4	6.1	9.1
Stored with mums	9.5	7.9	9.0
Stored in moving air	10.6	7.0	9.6
Stored in still air	9.3	8.7	9.1
Stored at 33°	10.3	8.5	9.7
Mean	10.0	8.4	9.6

In Experiment 8, (Table 6) a comparison was made between the preconditioned checks and checks placed immediately into the keeping rooms. Flowers without preconditioning kept an average of 2.5 days less than those preconditioned. The difference was slightly greater for open flowers. This experiment, together with some preliminary observations indicated that flower handling, regardless of storage treatment, can subtract keeping life.

Table 7. CA storage on keeping of Scania carnations stored for 5 days in polyethylene bags initially charged to 70% CO_2 or 9% O_2, respectively, at 4 temperatures.[1] Experiment 3.

Temperature	CO_2	N_2	Mean
50	12.6	11.6	12.1
45	11.4	13.3	12.4
40	11.4	13.0	12.2
33	12.4	12.4	12.4
Mean	11.8	12.6	12.3

[1]Check keeping life: 7.4 days. Flowing air for 5 days: 11.5 days.

Table 8. Results of Experiment 4. CA storage on keeping of Red Gayety carnations stored for 10 days, at different temperatures, in sealed polyethylene bags charged with CO_2 and N_2 on the 1st and 5th days.[1]

Temperature (°F)	CO_2		N_2		Mean		Mean
	Buds	Open	Buds	Open	Buds	Open	
50	4.5	0.9	7.6	1.0	6.1	0.9	4.1
45	11.6	9.5	12.5	13.3	12.0	11.3	11.7
40	10.4	12.0	11.7	12.9	11.3	12.3	11.8
33	11.9	12.1	12.9	13.7	12.4	12.8	12.6
Mean	9.4	9.1	11.0	10.5	9.8	8.1	
Mean	9.3		10.8				10.0

[1]Check keeping life: Open flowers -- 10.6 days. Comparison treatment in flowing air: -- 13.4 days.

The variations of keeping in commercial flowers would tend to reduce any advantages CA storage might have by giving inconsistent results. Improper handling before, during, and after storage would also reduce the value. Such problems must be considered in the economic feasibility of installing CA storage.

General results -- Tables 6 through 9 present results of some other experiments. In comparing keeping life of buds versus open flowers, cutting flowers as buds did not reduce keeping life. However, buds appeared to have the advantage when carnation cut flowers were subjected to severe stress such as that resulting from high temperatures. Regardless of the gas mixture used, increasing temperature much above 33°F consistently reduced keeping life.

In Experiment 5, the use of flowing nitrogen resulted in fermentation at all temperatures. At 60°F,

Table 9. Results of Experiment 6. CA storage on keeping life of Scania, stored as buds, and Red Gayety, stored as open flowers (3 weeks), at different temperatures and an oxygen concentration between 0.4 and 1.0%.

Temperature	Buds Scania	Open Red Gayety	Mean
50	6.7	3.5	5.7
45	9.6	5.5	8.3
40	10.1	7.4	9.4
33	11.4	8.2	10.6
Flowing air at 33	11.1	10.4	10.9

[1]Check keeping life: Buds 9.8 days. Open -- 7.7 days. Keeping life of buds stored for 6 weeks at 33°: Low O_2 -- 8.8 days. Flowing air -- 10.3 days.

in Experiments 9, 10 and 11, the flowers fermented. High flow rates used to purge tanks in Experiment 11, appeared to be the cause of severe bleaching (Fig. 1).

Summary

It is possible that equipment limitations in this study prevented accurate enough control to pinpoint an oxygen concentration that would permit the use of CA storage. Based on oxygen diffusion rates through tissues, it is possible to surmize that critical O_2 levels would be somewhere below 1.0%. However, the carnation flower is composed of several types of tissue of varying thickness and age as compared to an apple. A level suitable for the leaf may not be desirable for flower petals. There is probably a high interaction between temperature, previous history, variety, and gas concentration which were not fully explored in this investigation. It is also possible that CO_2 levels below 4.0% may be suitable. Until such time that the variability in potential keeping life of the flowers can be reduced to a minimum, the precise interactions as they relate to optimum gaseous concentrations will be difficult to determine.

There has been an increased interest in CA storage for cut flowers, some of it marked by considerable publicity. Contrary to some of the relatively optimistic reports, we have obtained no firm indications that CA will be economically feasible. The choice of some experiments in this study leave something to be desired, and indicate that useful recommendations will not be easy to come by. We can state that for CA storage to be useful, it must maintain keeping life of carnations when stored 2-1/2 months or longer; or, keeping life must be increased over any storage practice now in use.

Literature Cited

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Ed. note: It is often customary to publish only positive results. We feel that this is sometimes a mistake. These results are published in the hopes that we can save researchers and wholesalers some of the costly experiments related in this paper.

your editor,
W D Holley

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