Effects of Modified Atmosphere Packaging on the Longevity of *Phalaenopsis* Florets

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Additional index words. ornamentals, oxygen, carbon dioxide, storage

Summary. The packaging of flowering *Phalaenopsis* sp. orchids in sealed plastic film offers potential advantages of extending shelflife and maintaining quality by slowing respiration and protection from the hazards of retail distribution. Following treatments, 2-year-old plants, each with three to nine open florets, were stored at 21 to 27C for 76 days under natural light and natural daylengths. Plants were sealed individually in bags of air, or in bags of initially 15% O₂, 23% CO₂, balance N₂, or 20% O₂ and 30% CO₂. Control plants were left in open air and were watered twice weekly; plants in sealed bags were not watered. Gas concentrations in the sealed bags were monitored twice weekly. The various atmospheres had no effect on floret life. Two distinct patterns of O₂ and CO₂ variation with time were observed, but inflorescence half-life values were not related to these patterns. Florets on plants in bags had a greater incidence of discoloration.

Phalaenopsis are attractive, long-lasting potted plants for which current demand exceeds supply; therefore, they have the potential for greatly expanded commercial

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Technical Contribution No. 3456 of the South Carolina Agricultural Experiment Station. Mention of a proprietary product does not imply its endorsement by us or by Clemson Univ.

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sales. Their environmental growth requirements (i.e., 18C, 1500 ft-c) make them adaptable to home conditions, more so than *Cattleya* and *Cymbidium* spp. Their commercial potential has not been realized, partly because packaging for marketing through retail outlets such as supermarkets has not been developed. Also, like other orchids, they are particularly sensitive to ethylene (e.g., "dry" sepals and faster aging, etc.), a gas naturally produced by aging plants and fruit. Ethylene levels are a concern in supermarkets because flowers and potted plants often are displayed with produce. Barrier packaging such as hermetically sealed barrier plastic bags offers possibilities for extending the shelf life of *Phalaenopsis*: It can preclude exposure to environmental ethylene and could contain a gaseous mixture that preserves floret life. Floret life also might be extended by slowing petal respiration in a low-O₂ environment maintained within the barrier bag (modified atmosphere).

The objective of this experiment was to investigate the possibility of extending floret life by packaging *Phalaenopsis* in barrier plastic bags in atmospheres high in CO₂ and low in O₂ through their storage period. Previous experiments (unpublished data) on a smaller scale using a variety of modified atmospheres indicated the possibility that high CO₂ (20% to 30%) and moderate O₂ (2% to 20%) atmospheres have the potential to extend floret life. A secondary objective was to determine if the number of florets on an inflorescence affected floret longevity.

Although this research was not intended to be preliminary in nature, the variability encountered in the results indicated that a much more extensive study is needed. Further studies should better control plant size and stage of development. The results reported describe the best discernible patterns revealed after 4 years of research on modified-atmosphere packaging of cut flowers and flowering plants.

Past research. Controlled atmosphere (CA) storage of fruits and vegetables, in which the atmosphere is monitored continually and held within narrow limits, is a well-developed commercial technology (Metlitsliti et al., 1983). Modified atmosphere (MA) packaging, in which an initial atmosphere other than air or vacuum is

established in a package, is also a well-developed commercial technology for food packaging (Blankenship, 1985; Calderon and Barkai-Golan, 1990; ICCA, 1984; Ooraikul and Stiles, 1990; Robertson, 1993). For example, MA packaging is used commercially to extend the shelf life of broccoli and cauliflower florets (Packaging Digest, 1988).

For flowers, however, MA and CA storage has not been used extensively. Halevy and Mayak (1989) noted that this is due to difficulties in controlling optimum levels of O₂ and CO₂. Eisenberg (1985) presented eight reasons for the lack of interest in CA or MA storage of ornamentals. These include alternative solutions available for storage problems and the large number of cultivars involved, with little probability that a universal atmosphere can be found. An extensive review of the research on CA and MA storage of cut flowers supports this latter observation (Goszczynska and Rudnicki, 1988).

Only a few reports have appeared on MA packaging of potted plants. Harbaugh et al. (1976, 1978) evaluated the use of sealed polyethylene/polypropylene bags, but they did not carry out atmospheric analyses. As an example, their results for three cultivars of *Chrysanthemum morifolium* were remarkably different—one cultivar was 100% "marketable" after 30 days, while the other two were 0% "marketable." An earlier successful study with chrysanthemums sealed in polyethylene bags for 17 days was reported (Harrison et al., 1972). A patent for a sealed package for potted plants was granted in 1978 (Shore, 1978). In the only reported study of MA storage of orchids (Akamine, 1981), cut florets were stored for 2- or 3-day periods. Optimum levels of 1.5% to 2.0% CO₂ and ≈ 5% O₂ were found, based on resistance to fading of Tranda 'Miss Joaquim'.

Methods and procedures

Phalaenopsis plants. Two-year-old, white *Phalaenopsis* seedlings from the same cross were obtained from Carter and Holmes Orchids, Newberry, S.C. Each plant was in a 900-cm³ pot and had initiated three to nine florets—some fully opened at treatment application. Plant heights ranged from 25 to 66 cm. All the open florets were ≈ 8 cm wide.

Preparation of plants. Initially, all the plants were watered thoroughly. Each plant and its flowering stem then was sprayed lightly with Domain, FL (a.i. 46.2%) (Grace-Sierra) at 2.98 ml-liter⁻¹ for Botrytis control. The following day, the 40 plants were divided at random into four groups of 10 plants each per treatment and arranged in a completely randomized design until final data were recorded. The number of florets on an inflorescence was ignored in randomly dividing the plants.

Barrier bags. The 6-pm-thick polymer film bags used were clear multilayered bags fabricated of Cryovac 5401, a film normally used for packaging meat or poultry. The bags measured 38 × 66 cm. Permeability values were measured for this experiment using a Macon Oxtran for O₂ and a Macon Permatron-W600 for moisture. Standard ASTM Methods D-3985 and F-1249 were used, respectively, for O₂ and for water vapor. The volume of each bag was ≈ 23 liters after sealing.

Gas mixtures. Gas mixtures were prepared using tanks of compressed O₂, CO₂, and N₂, each regulated to a pressure of 0.21 MPa. Individual flow-regulating valves were attached to the gas lines. The gas lines were connected to a manifold, in which the gases mixed. A single tube from the manifold brought the mixed gas into individual bags. The valves were adjusted to produce predetermined gas mixtures. Valve settings were determined by a trial-and-error process of filling a bag, sealing it, then analyzing its gas content. When the target gas mixture was produced initially empty sealed bags, the valve settings were unchanged. Bags filled with plants then were purged individually and sealed with the target gas mixture.

Modified atmosphere sealing. Control plants were not bagged, but simply subjected to ambient conditions. The second treatment consisted of plants sealed individually in bags of air; the third of plants sealed in a gaseous mixture of ≈ 15% O₂, 23% CO₂, and balance N₂, and the fourth of plants sealed in a gaseous mixture of 20% O₂, 30% CO₂, and 50% N₂. To maintain high RH, an 8-cm³ sponge containing ≈ 7 ml of water was placed in each bag. A septum on each bag allowed for gas sampling, as required. Sealing was accomplished with a 150C resistance bar applied for 1 sec.

Sample storage. Plants were placed in a 21-27°C laboratory for subsequent observations. They received natural (at plant level) light and natural daylengths (from 21 May to 15 Aug.: 14 h, 9 min, increasing to 14 h, 32 min, then decreasing to 13 h, 30 min). The natural light was from windows with exposures around three sides of the storage room (north, east, and south). Atmospheres were monitored for 64 days, but the experiment lasted for 76 days, until all the florets had wilted.

Atmosphere determinations. One-milliliter gas samples were drawn twice weekly from each bag via a syringe inserted through a septum. The first samples were taken 1 day after the bags were sealed, and subsequent samples were taken every Tuesday and Friday, following an initial Friday sampling.

Gas samples were analyzed for O₂, CO₂, and N₂ using a Fischer-Hamilton Model 29 gas partitioner. This gas chromatograph is equipped with two columns in series: a 30% DEGS on 60/80 Chromosorb PNAW (6 ft × 0.25 inch) and a 80/100 molecular sieve 5A (6 ft × 3/16 inch) run at 20°C with a continuous helium flow of 32 cm³·min⁻¹. Each analysis required ≈ 12 min.

Evaluation of inflorescence life. Each inflorescence was examined six times per week. In previous trials, attempts were made to record the stages of quality degradation of the florets. Because each floret had been found to exhibit an individual progression of changes, in this study florets were recorded as either wilted or not wilted. A floret was rated as "dead" when its petals began to wilt, usually 2 to 3 days after its pedicel changed from green to white while forming an abscission layer. At each examination, the number of nonwilted florets was recorded. To allow for differing initial numbers of florets, the life of each plant's inflorescence was defined as the length of time following treatment application until one-half of its florets wilted. For plants with an odd number of florets, inflorescence life was based on the date midway between the date when more than half and that when just less than half the number of florets wilted.

Results

Permeability determination. The measured value for oxygen per-

Table 1. The effect of four treatments on storage life of potted *Phalaenopsis* sp.

Treatment	Atmosphere	Inflorescence life (days)		σ _{n-1} (SD)
		Mean	Range	
1	Control (open air)	38	16-61.5	17
2	Air (sealed in bag)	40	22.5-51	10
3	15% O ₂ , 23% CO ₂	43	31-60	9
4	20% O ₂ , 30% CO ₂	43	7-60	15

meation coefficient through the barrier film was 0.8 cm³O₂/mm per m² per atmosphere per day with a 100% O₂ gradient. For water vapor permeation, the measured permeation coefficient was 0.05 g/mm per m² per day with a relative humidity difference of 100%. Both measurements were made at 23°C.

Half-life of inflorescence. The mean half-life values of the four treatments (Table 1) were not significantly different ($\alpha = 0.05$). The longevity of the inflorescences was the same whether they are left in open air and watered every 3 or 4 days, sealed in air, or stored in elevated CO₂ atmospheres.

Changes in gas concentrations during storage. The initial CO₂ concentration for plants initially sealed in air averaged ≈ 6%; much higher than expected (Fig. 1). The O₂ and CO₂ average values for these plants remained in a narrow range over the course of the experiment. The CO₂ concentra-

tion gradually decreased to -3.5%. The O₂ concentration decreased to ≈ 13% between days 15 and 19, then slowly increased to ≈ 16%.

All of the plants initially sealed in air, and four of the 10 plants initially sealed in 15% O₂ and 23% CO₂, exhibited atmospheric change patterns similar to that in Fig. 1. The pattern consisted of two curves that did not intersect. The O₂ concentration remained above the CO₂ concentration for the duration of the experiment. Five of the 10 plants initially sealed in 20% O₂ and 30% CO₂ also exhibited this pattern.

For plants originally in 15% O₂ and 23% CO₂, the initially measured CO₂ concentration, at ≈ 11.5%, was lower than expected (Fig. 2). The CO₂ concentration, on average, increased above the O₂ concentration after day 15. The O₂ concentration decreased at the same time. The average CO₂ concentration remained above the O₂ level until after day 43. The O₂ concentra-

Fig. 1. Oxygen and CO₂ concentrations around potted *Phalaenopsis* sp. sealed initially in air (mean values for nine plants).

Fig. 2. Oxygen and CO₂ concentrations around potted *Phalaenopsis* sp. sealed initially in 15% O₂, 22.5% CO₂, and 62.5% N₂ (mean values for 10 plants).

tion continued to increase after day 43, while the CO₂ concentration continued to decrease. Six of 10 plants initially sealed in 15% O₂ and 23% CO₂ exhibited atmospheric patterns in which CO₂ levels greatly exceeded O₂ levels for 20 to 30 days during the 64 days of atmospheric monitoring (Fig. 3). The pattern for mean atmospheric

values presented in Fig. 2 is a combination of six plants with a pattern seen in Fig. 1 and four plants with a pattern seen in Fig. 3.

Figure 4 presents the data for mean O₂ and CO₂ concentrations around plants initially sealed in 20% O₂, 30% CO₂, and 50% N₂ atmospheres. The pattern is similar to that seen in

Fig. 3. Example of O₂ and CO₂ concentrations around one potted *Phalaenopsis* sp. sealed initially in 15% O₂, 22.5% CO₂, and 62.5% N₂.

Fig. 2. The initial measured concentrations for O₂ and CO₂, respectively, for these plants were $\approx 18\%$ and 13% . The initial CO₂ concentration was much lower than expected. The data presented in Fig. 4 resulted from five plants that exhibited a pattern seen in Fig. 1 and five plants with a pattern seen in Fig. 2 or 3.

The mean life of inflorescences of plants exhibiting atmosphere-time patterns exemplified by Fig. 1 was 43.1 days ($\sigma = 9.6$ days); for those of the pattern seen in Fig. 3, it was 39.8 days ($\sigma = 14.9$ days). Applying a *t* test analysis, the mean lives of inflorescences for the two types of atmosphere patterns are indistinguishable at 95% and even at 80% levels of significance.

Number of florets effect on longevity. Data in Table 2 compare inflorescence life to the total number of florets on the plant. Of the 40 plants studied, only three had five original florets, and the standard deviation for their inflorescence life is understandably large.

A *t* test analysis indicates that the means for inflorescence life are not distinguishable at an 80% level of confidence. A correlation analysis of these data indicates that there is no significant linear relationship between inflorescence life and number of florets (Pearson correlation coefficient, $r = 0.14$). Both results indicate that the random grouping of plants that ignored the number of florets on each plant was appropriate in this research.

Appearance of plants and florets sealed in barrier bags. No difference was apparent in the appearance of the leaves of the plants sealed in modified atmospheres for the 76-day duration of this study. No plants wilted.

Some of the florets sealed in barrier bags, however, exhibited petal discoloration when their petals made contact with moisture condensed on the inside of the bags. None of the florets on the control plants had observable discoloration.

Discussion

Results reveal that none of the modified atmospheres studied increased inflorescence life over that of *Phalaenopsis* simply placed in air. The fact that CO₂ levels increased to $\approx 30\%$ while O₂ levels decreased to $\approx 5\%$ (as seen in Fig. 3) without affecting floret longevity suggests that floret longevity is not strongly dependent on stor-

Fig. 4. Oxygen and CO₂ concentrations around potted *Phalaenopsis* sp. sealed initially in 20% O₂, 30% CO₂, and 50% N₂ (mean values for 10 plants).

age atmosphere over these values. The use of air as the initial atmosphere, of course, simplifies and lowers the cost of packaging in a sealed environment.

The gas concentrations in the barrier bags did not change abruptly when florets wilted. The respiration and photosynthesis of the leaves of the plants appear to have dominated any effects caused by changes in the florets. As pointed out by Eisenberg (1985), one of the reasons "CA storage work in ornamentals is lacking" is the fact that they include leaves, roots, and flowers, "and each reacts differently to CA." The atmospheres measured in this study were summations of reactions occurring in different plant parts.

The advantages of storing in barrier bags are: The plants can survive without being watered and they are not subjected to potentially harmful environments (e.g., ethylene). Harbaugh et al. (1978) observed the

former. This is significant if plants such as *Phalaenopsis* are to be distributed via efficient distribution systems now used for mass retail marketing.

The presence of condensate in the bags and floret discoloration associated with it suggests that the polymer bags or other packaging chosen to package flowers for mass market retail distribution should be selected for their water vapor permeation properties. Ideally, bags should be sufficiently moisture-permeable to prevent excessive moisture buildup or condensate.

To avoid petal discoloration, a rigid package and a means of supporting the peduncle to keep the florets from contacting the package are both desirable.

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Table 2. The effect of number of florets on inflorescence life of potted *Phalaenopsis* sp.

No. florets	Inflorescence life (days)		σ _{n-1} (SD)
	Mean	Range	
3	38.3	22.5-45	12.8
4	37.3	21-51	10.5
5	30.3	16-53.5	20.2
6	48.6	32-60	10.2
7	45.7	38-55.5	6.3