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LOW OXYGEN AS A STORAGE METHOD
FOR VERNALIZED LILIUM 'ENCHANTMENT'
BULBS

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Mollie Stark Callow

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LOW OXYGEN AS A STORAGE METHOD FOR VERNALIZED

LILIUM 'ENCHANTMENT' BULBS

By

Mollie Stark Callow

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ABSTRACT

LOW OXYGEN AS A STORAGE METHOD FOR VERNALIZED *LILIUM* 'ENCHANTMENT' BULBS

By

Mollie Stark Callow

Vernalized lily bulbs (*Lilium* 'Enchantment') were held in 2, 4, 8, and 21% O_2 for 2 or 4 weeks at 20C following cold storage (-2C) for up to 4 months. Two percent oxygen inhibited shoot elongation. Regrowth potential was superior in bulbs held in low oxygen environments. Although bulbs flowered later, they had more flowers, a longer lasting inflorescence and no bud abscission. Duration of cold storage had a detrimental effect on regrowth potential as well as holding bulbs at 20C following cold storage, regardless of O_2 level. Flowering quality of bulbs held in low O_2 was inferior to controls. A preliminary packaging study was done using LDF-301 low density polyethylene film. Oxygen levels within the range of 2-8% were obtained within sealed bags. However, regrowth potential upon forcing was inferior to that of bulbs in bags with holes, despite the latter's 33% water loss.

DEDICATION

This thesis is dedicated to the memory of Anne Hartung. She was a friend, a colleague, and a truly great person. I miss her very much.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Art Cameron, for the support, respect, and editorial assistance he generously gave me throughout my graduate studies. Thanks also are due the other members of my committee, as well as to Sharon Schwab for her technical assistance.

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INTRODUCTION

Lilium 'Enchantment' with its bright orange flowers, is one of the most popular of the lily hybrids There is much interest in marketing a bulb that can be forced throughout the year in or out of doors, depending on the climate. Production involves vernalization for 6 weeks at 2.5C to initiate flowering followed by optional cold storage at -2C to ensure year-around availability of bulbs (2,5,6). Bulbs are removed from cold storage and either marketed as is or potted for cut flowers or as a whole plant (3).

Once lily bulbs grow to maturity, regardless of receiving their vernalization requirement for flowering, they begin to produce a fragile shoot which is easily broken off. Even among vernalized bulbs, no flowering will result if the shoot is damaged in this way.

The six week vernalization requirement has been found to be optimal for the quickest flowering and least amount of adverse effects on regrowth potential (6). Long-term cold storage can produce adverse effects on regrowth potential since these temperatures, though not ideal, do continue to have vernalizing effects on the stored bulbs (6). The bulb will flower faster, but there will usually be a corresponding decrease in bud number, inflorescence duration and attractiveness of stem habit growth. Abscission rate may increase. Adverse effects may become progressively worse with increasing duration of cold storage, especially if storage conditions are not optimal (1,4,6).

We hypothesized that low oxygen would perhaps inhibit shoot elongation and offset decreased regrowth potential. A low oxygen environment can be created within a polyethylene film package. A film packaging system could be designed to hold and preserve lily bulbs during the marketing period.

The objective of this research was first to attempt to establish optimal O_2 levels that would inhibit shoot elongation and maintain plant quality equal to controls. Then a modified atmosphere package system was evaluated for use as a marketing technique.

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LITERATURE REVIEW

The lily bulb (*Lilium* sp.) is, morphologically, a modified underground stem. This highly specialized structure has overlapping, fleshy scale-leaves arranged concentrically about a central compressed stem (13). The stem is a much flattened or cone-shaped structure also called the basal plate (20). Unlike a tulip bulb, the lily bulb is not enclosed in an outer skin.

Lily bulbs are usually harvested from September through October in the northern hemisphere. The fleshy, fibrous root system, which originates from the basal plate, is left intact. This exposed root system, along with the absence of a protective outer skin, leaves the bulbs vulnerable to desiccation during long, dry storage.

While the aerial stem is growing and developing flowers, one or more daughter bulbs are formed by lateral growing points in the axils of the bulb scales near the flower stalk (20). The new daughter bulbs are the overwintering structure of the plant. Daughter bulbs are also an important sink during periods of cold or drought (20).

All true lilies bear a racemose inflorescense composed of one to many six-petaled flowers situated toward the top of the stem with each flower on its own pedicel (13). At the end of each growing season the aerial stem dies back to the bulb (20). Following sufficient vernalization, the daughter bulb(s) is ready for next season's growth (20).

Before a lily bulb will begin to grow a flower stalk, it must first receive a cooling period. Lily bulbs are usually cooled for six weeks at a temperature of 1.5C to 7C (34). Miller and Kiplinger (22) describe this cooling as 'vernalization' because exposure to temperatures between 1C to 6C hastens flowering inductively, not directly. Flower initiation occurs several weeks after removal from cold treatment when the stem has reached 6-7 cm (6).

Vernalization produces a different habit of plant growth than observed from bulbs not cooled and forced at temperatures between 10C-20C. A vernalized bulb flowers earlier, has fewer flowers, and a shorter stem (6,34).

It is imperative that lily bulbs be cooled and stored under optimal conditions to ensure best floral quality. The intact root system must not be allowed to wither and die since these roots are necessary for uptake of water and nutrients after planting (13). Desiccated bulbs require longer for forcing than plump, turgid ones, and produce fewer flowers (6,35).

Lily bulbs are usually packaged for storage either 'dry' (in cedar shavings, for example) or 'moist' (in peat moss) (21, 35). Moist packing medium should contain a slightly lower percentage of moisture than the bulbs (35). Lining the bulb cases with sheets of polyethylene plastic film effectively prevents water loss and the moisture level of the bulbs can be maintained at nearly the initial level throughout storage (35). Overly moist or dry bulbs may suffer from a lack of oxygen or become dehydrated, respectively. Consequently, they may not respond to cold treatment in the same manner as healthy bulbs (6).

Forcing can be accomplished in the greenhouse year around if properly treated and stored bulbs are available. During the winter, supplemental lighting is necessary in regions of short, overcast days (9). Lilies grown under either low light intensity or short daylength are subject to both bud blasting and bud abscission (9,39). Flower bud blasting is characterized by bleaching of the green color at the base of the bud, or a dull orange discoloration of the bud and withering (9). Ultimately, the buds show a brownish necrosis, become desiccated and eventually fall off, leaving the pistil behind (9). Bud blast is usually restricted to the top flower buds of the inflorescence (9). Flower bud abscission is marked by a similar bleaching of the bud

(9). However, the entire bud falls off and this process is accompanied by leakage of orange liquid from the anthers. Abscission starts in the lowest buds of the inflorescence (9). Bud blasting can occur any time throughout flowering, but abscission occurs only during a critical stage that is reached 6 to 7 weeks after emergence. This has been correlated with the end of the meiotic phase of the stamens as well as with a peak in endogenous production of ethylene (10,18). At this point the lower buds are 2-3 cm long (10, 39,40). High temperatures promote both blasting and abscission of buds, but radiant energy has been shown to be the crucial factor (40). Kamerbeek and Durieux (17) suggest that inadequate light is probably the most important factor in promoting bud blasting and abscission. Further results of this study (17) showed that plants from bulbs of the cultivar, Lilium 'Enchantment', stored for longer periods of time, showed a lower percentage of abscissed buds. Both ethylene production by the buds and flower bud abscission are influenced by the length of time the bulbs have been stored before planting (17). Durieux et al. (9) speculate that a change may occur during bulb storage of some factor(s) within the plant and correlated with both abscission and ethylene production in the buds.

Jerzy and Krause (16) recommend supplemental lighting of 2000 lx for ten hours a day during the first six weeks of growth followed by 4000 lx continuously once the lowest buds have reached 0.5 cm in length. Though stem height is reduced by increasing cold storage duration, some researchers have found that stem height is unaffected by light intensity (11,16,19). Other research has shown that the use of supplemental lights to extend daylight will increase height (3,6). However, Stuart (36) showed an adverse effect. He found that lily bulbs (L. speciousum rubrum 'Lucie Wilson') grown under supplemental lighting were slightly shorter than controls. Higher illumination in the 2000-3000 lx range can increase the number of flowers produced per plant (16). This can be advantageous since bud number is a characteristic that can be adversely affected by storage duration (7,16). Both increased storage duration and high light intensity have been found to decrease the time to flowering (7,16).

After vernalization, lily bulbs have traditionally been stored for many months at -2C and forced for cut flowers or sold in the spring for outdoor planting (8,9,21,33,34,35,36). A relatively new market has arisen for pot plant production of several lily cultivars (12,23,25,28). One of the most popular for pot plant production is the Asiatic Mid-Century hybrid, Lilium

'Enchantment'. The bright-orange, speckled flowers of Enchantment face upright in a flat-faced manner with petals curling under. The potential for pot plant production of lilies, such as Enchantment is unlimited. But there are several problems that must be addressed.

Immediately following the vernalization period, the bulb, when placed at room temperature, begins to increase its respiration rate and produce a shoot whether under optimal growing conditions or not. Consequently, such a bulb becomes doubly fragile because it bears a thin shoot which is easily broken off. If the shoot is damaged during the marketing period, no flowering will occur.

Tulip bulbs (Tulipa sp.) do not produce a shoot as rapidly as lily bulbs, but their metabolic processes also increase after cooling (24,26). If left unplanted at room temperature (20C) a large percentage of bulbs will produce blasted tulips (24,26). Prince (26) suggests that the high respiration rate during high temperature storage after special precooling may deplete the carbohydrate supply and lead to inferior flowering. He found that low oxygen (O_2) storage (3% or 5% O_2) of tulip bulbs at 17C for 4-6 weeks did not impair flowering and reduced ethylene-induced flower-bud abortion during storage.

Low oxygen storage could also be beneficial to lily bulbs. Besides inhibiting stem elongation due to reduced respiration rate, a modified atmosphere environment may also inhibit ethylene production, which can cause flower-bud abscission (1,24, 25). Decreasing the respiration rate could be a means of lowering the metabolic rate and reducing the rate of change (5).

Sporadic research on the effects of low O_2 on lily bulbs has occurred for the last 50 years. In 1941, Thornton (39) investigated the effects of different mixture of O_2 and carbon dioxide (CO_2) on development of dormancy in Easter lilies. He found that 40% CO_2 coupled with 2 to 20% O_2 caused a retardation of both premature shoot emergence and subsequent growth and flowering of the plants produced.

Beginning in the 50's researchers concluded that film wrapping of horticultural commodities was not feasible unless the film was perforated (2,14,29,32). Much of the early work was performed without optimizing parameters, such as film permeability, package size, weight and respiration rate of a commodity. The problem may have been insufficient oxygen permeability of the films tested.

Prince (27) found that the equilibrium gas concentrations within the optimized low-density polyethylene packages of 5 bulbs each were 5% O_2 and 4% CO_2. These concentrations, as well as package type and size, had been determined beforehand to be within the optimal range (27). Excellent flowering was obtained upon forcing after 4 weeks of storage at 20C.

Most of the research for this thesis concerned establishing an optimal oxygen level for storage of Enchantment lily bulbs. This O_2 level or range must be able to ensure quality flowering and growth in the shortest time possible. Studies were also conducted to learn how long-term cold storage interacted with low oxygen treatment and the potential for use of a modified atmosphere packaging system.

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SECTION 1

ESTABLISHING OPTIMAL LOW OXYGEN LEVELS FOR STORAGE OF VERNALIZED *LILIUM* 'ENCHANTMENT' BULBS

INTRODUCTION

The year-round sale of vernalized lily bulbs for home potted plants is a fast-growing industry. The cultivar, *Lilium* 'Enchantment', a hybrid of *Lilium tigrinum*, is considered by many to be the best commercial lily ever introduced (19). Through proper greenhouse programming bright orange flowers can be produced throughout the year (19). More bulbs of this cultivar are currently grown than all other lilies combined including the Easter lily (19).

Marketing techniques developed for vernalized Enchantment bulbs have not addressed adequately the problem of premature shoot elongation, particularly for bulbs held at room temperature. Low temperature storage delays sprouting (32), but refrigerated marketing displays are not currently employed.

In many instances bulbs are removed from cold storage and left uncovered at room temperature while displayed for sale. This usually results in desiccation of outer scales and roots and in rapid shoot elongation. The elongated shoot can be damaged easily and desiccation can cause poor regrowth, all to the dissatisfaction of the consumer (8,34).

Little research in this area of postharvest handling of lily bulbs has been done, perhaps because bulb production for potted lily plants other than the Easter lily is a relatively recent development.

In an early study, Thornton (35) investigated the effects of different mixtures of O_2 and CO_2 on dormancy of Easter lilies. He found that 40% CO_2, coupled with 2 to 20 percent O_2, caused a retardation of both premature shoot emergence and subsequent growth and flowering of the plants produced.

During the years following Thornton's study, researchers investigated many types of packaging methods for various kinds of produce. Prince (28) chose to determine the optimum film beforehand. First, he determined optimal low O_2 levels for storage at 20C. Then he found a film with the correct permeability to establish optimal equilibrium levels within a package made from the film. Lastly, he designed and tested a film package containing tulip bulbs.

Prince (28) found that a 3% oxygen atmosphere for four weeks at 20C (simulating the marketing period) prior to forcing reduced respiration rate during the treatment period and maintained flower quality potential.

In developing a similar modified atmosphere system for lily bulbs, consideration must also be given to the common practice of long-term storage of the bulbs at -2C

(11,13,23,30,31,32,34,35). This practice insures year-around availability of bulbs for use as pot plants and cut flowers, as well as for gardens in southern regions.

A research project was initiated to determine if low O_2 could be used in place of refrigeration to maintain quality of vernalized Enchantment lily bulbs during 2 to 4 weeks of simulated marketing at room temperature. The experiment also investigated the interaction of cold temperature storage at -2C with the low oxygen treatment.

MATERIALS AND METHODS

Plant Material

Lily bulbs of the cultivar Lilium 'Enchantment' (12.5-15cm in circum.) were harvested early October, 1984, in Sandy, Oregon, and shipped by truck to East Lansing, Michigan, on October 23, 1984. The bulbs arrived eight days later. The bulbs were reported by the grower/handler to have received about 10 days storage at 4.5C by their arrival time. After arrival, all bulbs were held at 21C for two weeks.

The bulbs were then vernalized at 2.5C for six weeks (7,9,34,35) before transfer to -2C. Throughout vernalization and storage, bulbs remained packed as they were shipped; in moist peat moss which had an average initial moisture content upon arrival of about 60% (data not shown) within polyethylene liner bags.

Treatment Application

Low Temperature

At intervals of 0, 1, 2, 3, and 4 months, bulbs were removed from -2C storage and held for 24 hours at room temperature on trays inside large, loosely closed plastic bags. Bulbs were then weighed and measured for shoot elongation.

Low Oxygen

A continuous gas flow system passed measured rates of humidified oxygen mixtures (2, 4, 8 and 21% O_2) at rates between 5.5 and 13.0 ml/min. through one pint (473 ml) jars containing individual bulbs. Carbon dioxide analysis of 1 ml samples taken every 2 to 3 days from the effluent stream of air was used to calculate respiration rates (28).

Gas Determination

Gas samples were analyzed on a Carle 8700 gas chromatograph employing a thermister detector and equipped with two columns in series. The first column was of silica gel for initial separation of carbon dioxide and the second column was of molecular sieve for separation of nitrogen and oxygen. Helium was used as the carrier gas and oven temperature was 70C.

Planting

Following treatment in the different oxygen environments for 2 or 4 weeks, all bulbs were reweighed to estimate water loss and remeasured for shoot elongation. All bulbs were planted in clay pots using a peat-perlite mix. Untreated controls were planted directly following each month of -2C storage.

When the length of the lowest bud on the stem reached approximately 10-15 mm, the plants were placed under high intensity lights. From February until June, lighting was continuous, while from late spring through mid winter, supplemental lighting was used only from 7 p.m. until midnight (5,6,13,38).

Regrowth Quality Evaluation

The following regrowth quality characteristics were measured for each plant: (1) the number of days from planting until the first flower fully expanded; (2) the inflorescence duration measured as the number of days from the first, fully-expanded flower until petal-fall from the final blooming flower; (3) total stem height as measured from the soil surface to the point of pedicel origin; (4) the length of the lower stem section with foliage; (5) the length of the upper stem section immediately below pedicel origin which may be free of foliage; (6) total number of buds/flowers; and (7) percent bud abscission.

Statistical Analysis

All experiments were conducted and analyzed as completely randomized designs. The regrowth data were analyzed as either 3-way factoral or one-way AOV's with 6 replicates per treatment.

An average of all the sample values of percent CO_2 used to establish respiration rate was calculated for each experimental unit and the data were analyzed as a 2-way AOV.

The LSD values at the 5% level were calculated as estimates of mean separation.

RESULTS

During Simulated Marketing Period

Shoot Elongation

Duration of the simulated marketing period greatly affected shoot elongation. After 2 weeks shoot elongation was less than 1 cm for all treatments (Table 1). However, following 4 weeks of simulated marketing in low O_2 or air, bulbs produced a shoot averaging 6 times as long. Averaged over all months, 2% O_2 significantly retarded shoot elongation (Table 1).

Table 1: Shoot elongation of vernalized L. Enchantment lily bulbs held at varying O_2 levels for 2 or 4 weeks (at 20C) following low temperature storage (-2C) for up to 4 months. Values are averaged over all storage durations.

%02	2 weeks	4 weeks
2	0.3	1.0
4	0.4	1.8
8	0.5	3.4
21	0.5	3.2
AVG	0.4	2.4

$LSD_{.05} = 0.4$

Bulbs stored at -2C produced more shoot elongation during simulated marketing compared to bulbs planted directly following vernalization (see Fig. 1). Low oxygen (2 and 4%) appeared to retard shoot growth compared to 8 and 21% O_2 after 2, 3, and 4 months of -2C. After 4 weeks of simulated marketing, the bulbs held at 2% O_2 produced 38% as much shoot growth as bulbs held in 21% (0.8 cm compared to 2.1 cm) (Fig. 1).

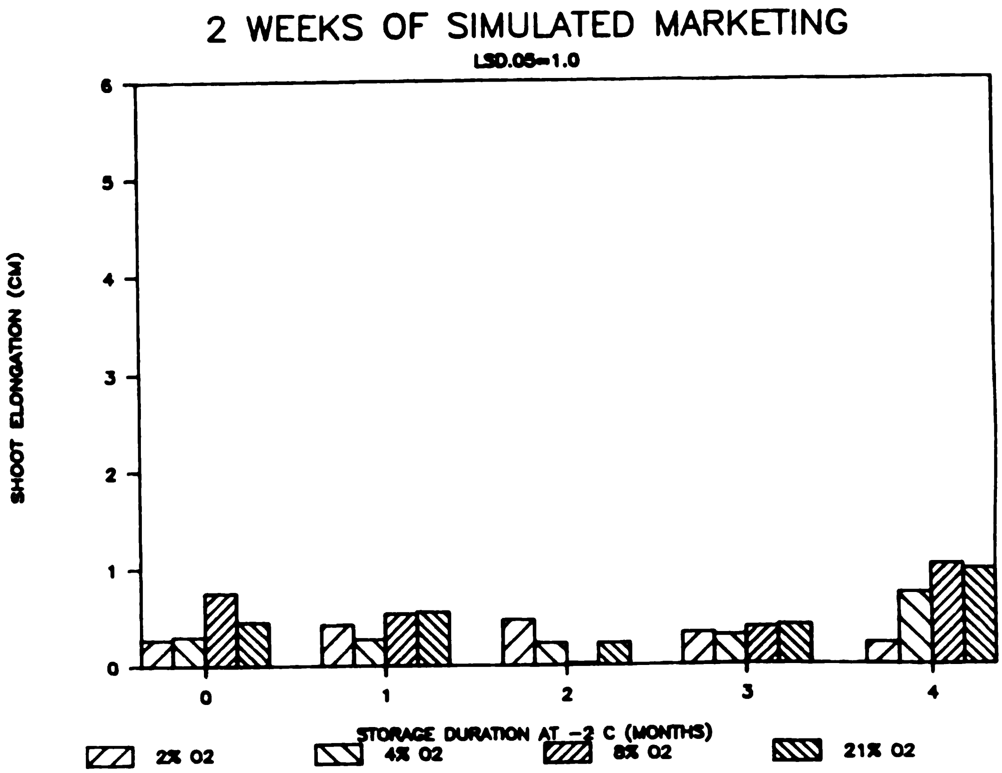
Water Loss

The rate of water loss after 2 weeks of simulated marketing was 4.3%, while after 4 weeks the rate was 6.3% ($LSD_{.05}$ = 0.4). Thus, twice as much water was lost during the first 2 weeks compared to the final 2 weeks.

Bulbs stored at -2C tended to lose more water during the simulated marketing period than did the nonstored controls (Fig. 2). Average water loss after any -2C storage was 20% greater than water loss in bulbs planted directly following vernalization (4.4% and 5.5% for nonstored and stored bulbs, respectively) (Fig. 2). There did not appear to be a relationship between moisture loss and storage duration at -2C.

Oxygen level had virtually no effect on weight loss (data not shown).

Fig. 1. Shoot elongation of vernalized *L.* 'Enchantment' lily bulbs during 2 weeks (top graph) or 4 weeks (bottom graph) of simulated marketing (at 20C) following cold storage (-2C) for up to 4 months.


2 WEEKS OF SIMULATED MARKETING
LSD.05=1.0
SHOOT ELONGATION (CM)
0
1
2
3
4
5
6
STORAGE DURATION AT -2 C (MONTHS)
2% O2
4% O2
8% O2
21% O2

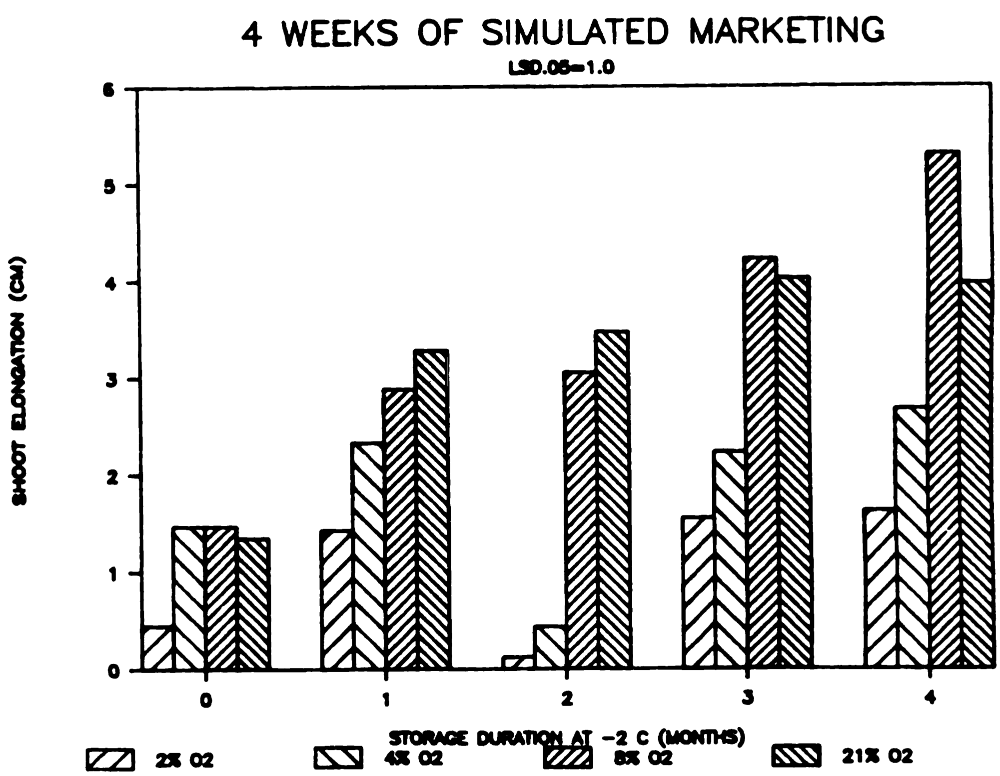
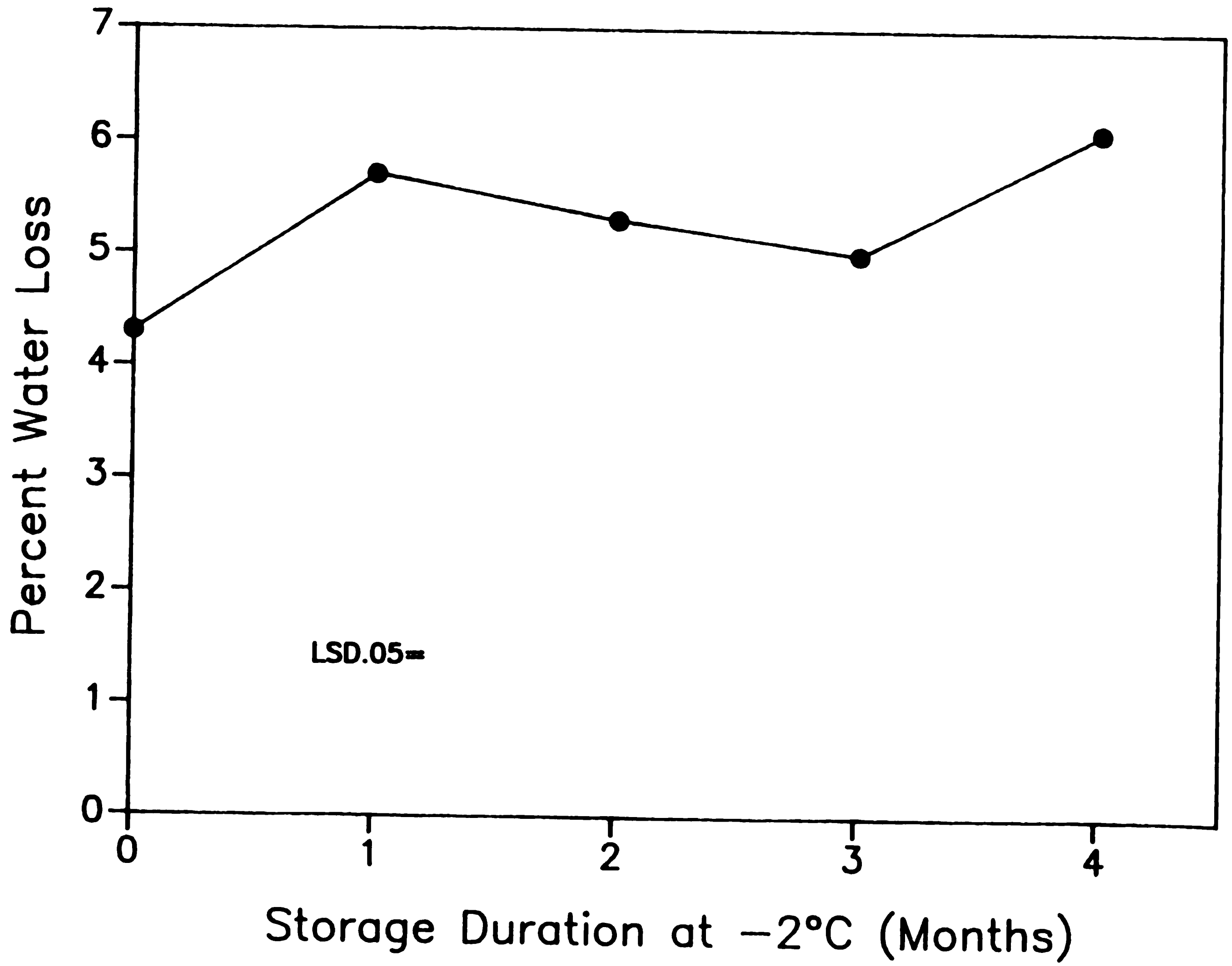

4 WEEKS OF SIMULATED MARKETING
LSD.05=1.0
SHOOT ELONGATION (CM)
0
1
2
3
4
5
6
STORAGE DURATION AT -2 C (MONTHS)
2% O2
4% O2
8% O2
21% O2

Fig. 2. Percent water loss of vernalized *L.* 'Enchantment' lily bulbs during up to 4 weeks of simulated marketing following -2C storage. Values are averaged over oxygen level.



Percent Water Loss
0
1
2
3
4
5
6
7
LSD.05=
0
1
2
3
4
Storage Duration at −2°C (Months)

Regrowth Characteristics

Days to First Flower

Bulbs tended to flower more quickly the longer they were held in simulated marketing conditions. For every 2 weeks of simulated marketing, time to first flower decreased by about 8 days (Table 2).

Table 2: Days to first flower of vernalized *L.* Enchantment lily bulbs held in simulated marketing for 0, 2, and 4 weeks following storage at -2C.

Months of Storage Duration	Weeks of Simulated Marketing 0	2	4	AVG
0	70	66	60	65
1	63	57	49	56
2	64	55	45	55
3	60	52	44	52
4	62	52	42	52
AVG	64	56	48	

Note: $LSD_{.05}$ = 2.8 (for 0 week data only)

$LSD_{.05}$ = 1.6 (for 2 and 4 week data only)

Storage at -2C also tended to decrease the number of days till first flower (Table 2). As storage duration increased, days to first flower showed a decrease.

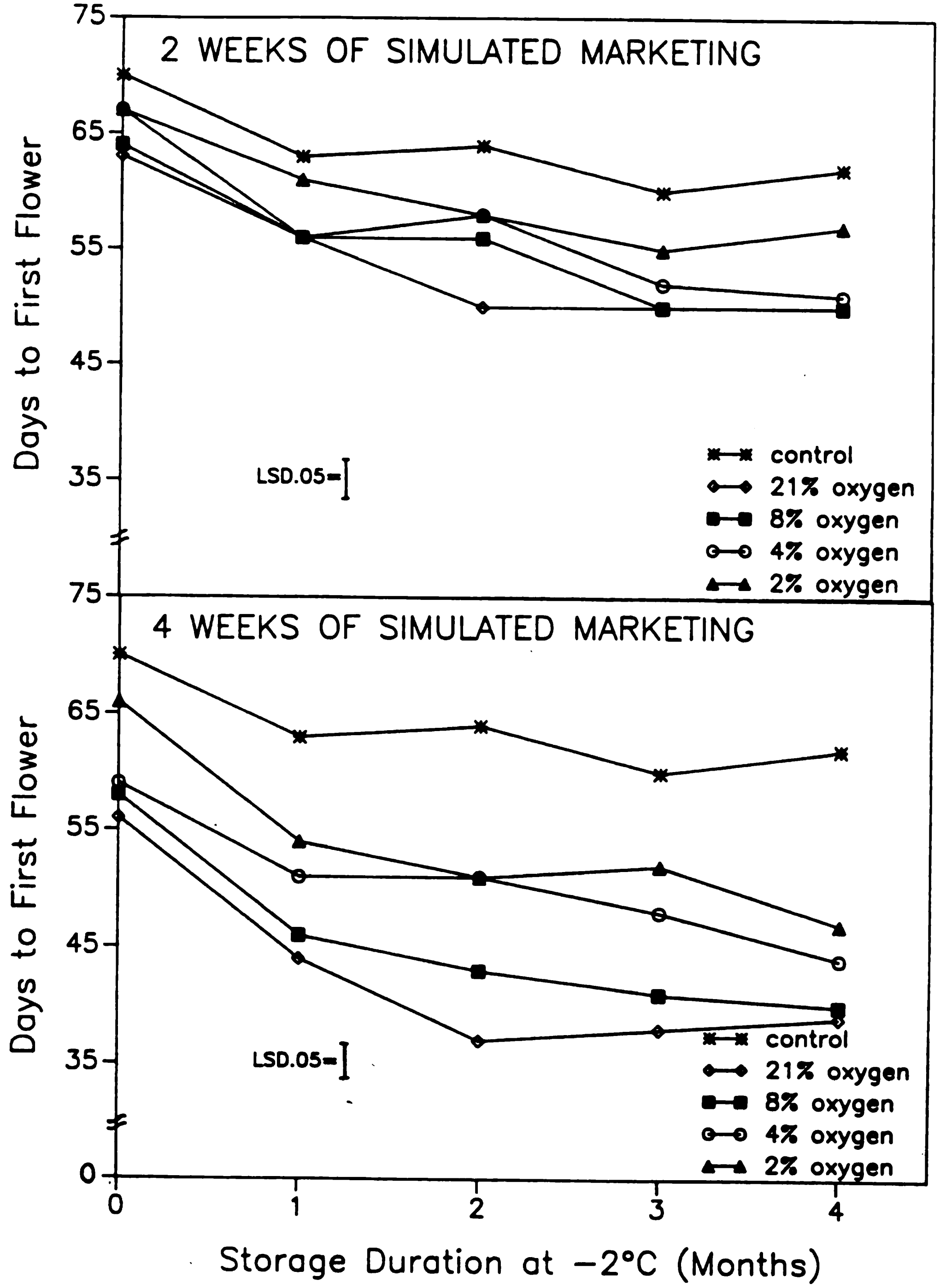
Low oxygen during simulated marketing appeared to increase time to first flower compared to air (Fig. 3). After 4 weeks and averaged over all storage durations, bulbs held in 2% O_2 bloomed nine days later than those held in air. As oxygen level increased from 2% to 21%, the number of days to first flower decreased. Among bulbs given at least one month of -2C storage treatment, the greatest number of days till first flower occurred from bulbs not given the simulated marketing treatment (64 days). This was 3.5 weeks longer than those held in air for 4 weeks following any storage duration (39 days) (Fig. 3). Control bulbs planted directly following vernalization and receiving no low temperature storage bloomed after 70 days.

Inflorescence Duration

The main effects of storage at -2C and duration of the simulated marketing period had a highly significant effect on inflorescence duration. Storage at -2C caused about a 25% decrease in duration of the inflorescence compared to nonstored controls (Table 3). Progressively longer storage did not further adversely affect the inflorescence duration.

Duration of flowering was reduced as the length of holding bulbs at 20C was increased (independent of low O_2 or storage duration) (Table 4). For every 2 weeks of

Fig. 3. The number of days to flowering of vernalized *L.* 'Enchantment' lily bulbs stored at -2C followed by a simulated marketing period at 20C for 2 weeks (top graph) or 4 weeks (bottom graph) prior to forcing. Controls were planted directly after cold storage and/or vernalization. LSD value is for oxygen data only.



2 WEEKS OF SIMULATED MARKETING
4 WEEKS OF SIMULATED MARKETING
Days to First Flower
75
65
55
45
35
0
LSD.05=
control
21% oxygen
8% oxygen
4% oxygen
2% oxygen
0
1
2
3
4
Storage Duration at −2°C (Months)

Table 3. Inflorescence duration of vernalized *L.* 'Enchantment' lily bulbs stored up to 4 months at -2C prior to simulated marketing at 20C.

Storage Period (months)	Inflorescence Duration (days)
0	14.2
1	10.2
2	11.0
3	11.2
4	10.3

Note: $LSD_{.05} = 0.9$

Table 4. Inflorescence duration of vernalized *L.* 'Enchantment' lily bulbs held for 0, 2, or 4 weeks at 20C storage at -2C for up to 4 months.

Length of Simulated Marketing	Inflorescence Duration (Days)
0 weeks	14.5
2 weeks	12.3
4 weeks	10.5

Note: $LSD_{.05} = 0.6$ (for 2 and 4 week data only) simulated marketing averaged over O_2 level and storage duration, there was a decrease of about 2 days in length of the bloom period.

Oxygen level had no significant effect on inflorescence duration (data not shown).

Stem Height and Habit

Storage at -2C caused a significant decrease in stem height by an average of 9 cm (Table 5). There was no linear decrease with progressively longer storage.

Table 5: Stem height of vernalized *L.* 'Enchantment' lily bulbs stored for various durations at -2C prior to simulated marketing at 20C.

Storage Duration (Months)	Stem Height (cm)
0	38.3
1	30.9
2	28.0
3	29.5
4	28.9

Note: $LSD_{.05}$ = 1.7.

Stem height decreased as simulated marketing duration increased from 2 to 4 weeks, independent of -2C storage or oxygen level (Table 6).

Table 6: Stem height of vernalized L. 'Enchantment' lily bulbs after 0, 2, and 4 weeks of simulated marketing at 20C following storage at -2C.

Length of Simulated Marketing	Stem Height (cm)
0 weeks	33.7
2 weeks	34.0
4 weeks	28.2

Note: $LSD_{.05}$ = 1.1 (for 2 and 4 week data only)

Oxygen level did not have a significant effect on stem height (data not shown).

The length of the lower stem section with foliage was reduced similarly to the overall stem height by storage at -2C and length of simulated marketing (data not shown).

Storing lily bulbs at -2C following vernalization increased the length of stem without foliage. One month exposure to -2C increased the upper bare section, but progressively longer cold storage did not further increase it (Table 7). Average length of bare stem section following any -2C storage was about 1.0 cm greater than in plants from nonstored bulbs.

Oxygen at less than 21% slightly increased the length of the bare stem section as compared to air (Table 8).

Table 7. Stem height without foliage of vernalized *L.* 'Enchantment' lily bulbs held in 0.2 or 4 weeks of simulated marketing conditions of 20C following either no storage or up to 4 months of storage at -2C.

Length of Simulated Marketing	Stored	Unstored
0 weeks	3.3	1.3
2 weeks	3.6	2.7
4 weeks	3.2	2.8

Note: $LSD_{.05}$ = 0.5 (for 2 & 4 week data only)

Table 8: Stem height without foliage of vernalized *L.* 'Enchantment' lily bulbs held in varying oxygen levels at 20C for 2 or 4 weeks following storage at -2C for up to 4 months.

%02	Stem Height Without Foliage (cm)
2	3.4
4	3.2
8	3.5
21	2.8

Note: $LSD_{.05}$ = 0.3

Bud Number

Low temperature storage combined with simulated marketing significantly decreased bud number compared to control bulbs planted directly following vernalization (Fig. 4). The longer the simulated marketing period, the fewer the number of buds (Table 9). For each 2 weeks of exposure to low O_2 or air, there was a decrease in bud number by about 2 buds.

Low oxygen levels did not significantly affect bud number (data not shown).

Bud Abscission

No abscission occurred among the control bulbs given no simulated marketing treatment or those held for 2 weeks during simulated marketing, regardless of O_2 level (Table 10). Bulbs held for 4 weeks of simulated marketing showed varying degrees of abscission with the greatest amount being 40% in bulbs treated 4 weeks at 21% O_2 after 3 months storage at -2C. No abscission occurred in bulbs held in 2% O_2 for 4 weeks.

Respiration Rate

Following storage at -2C, the respiration rate increased in bulbs held at 4, 8, and 21% O_2 at 20C during the simulated marketing period (Fig. 5). However, bulbs held at 2% O_2 for 4 weeks did not show an increased rate of respiration rate following cold storage.

Fig. 4. Bud number during forcing of vernalized *L.* 'Enchantment' lily bulbs which had been held in simulated marketing for 2 or 4 weeks at 20C following cold storage (-2C) for up to 4 months. Controls were planted directly after cold storage and/or vernalization. LSD value is for 2 and 4 week data only.

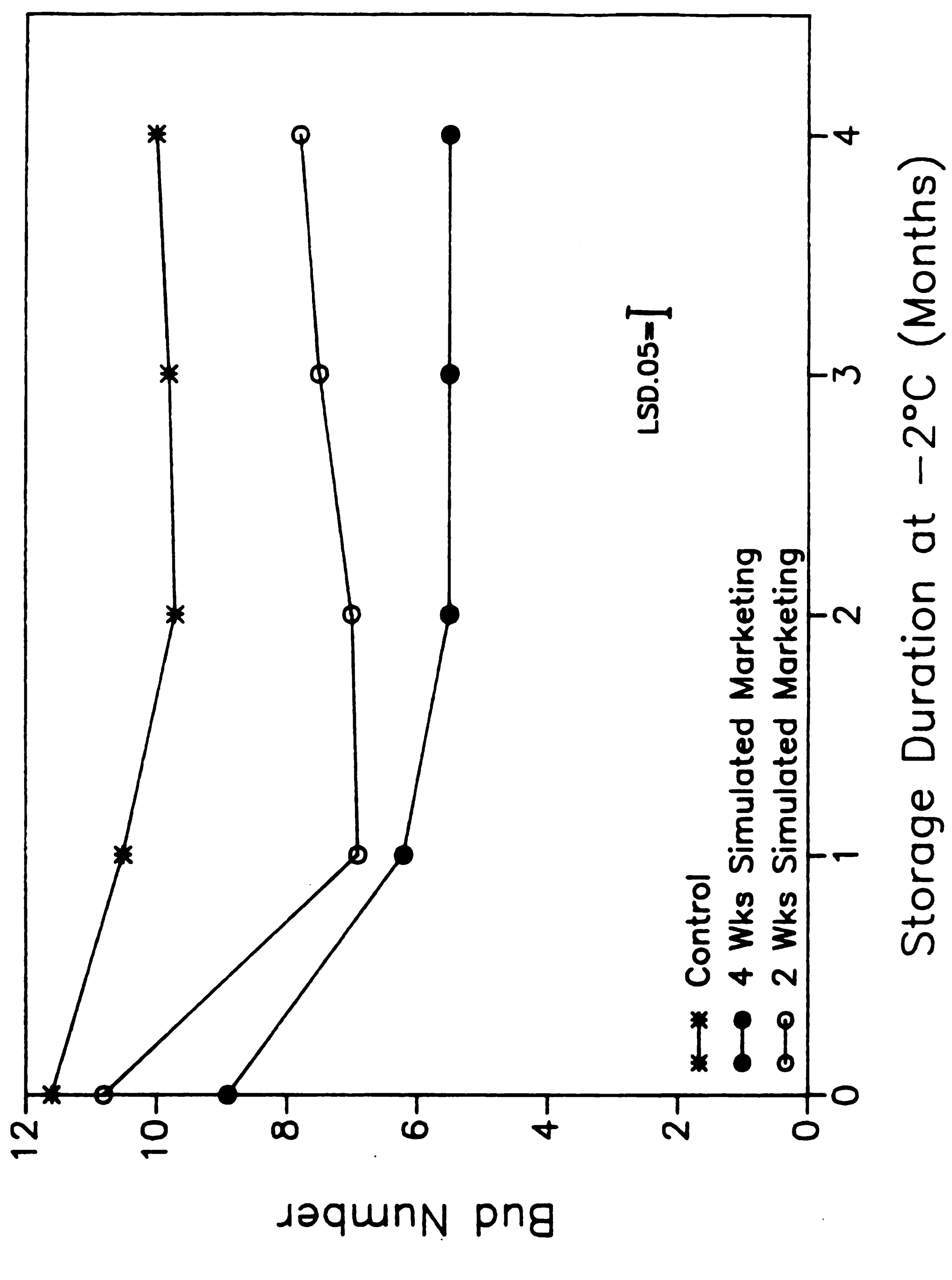

Bud Number
12
10
8
6
4
2
0
Storage Duration at −2°C (Months)
0
1
2
3
4
Control
4 Wks Simulated Marketing
2 Wks Simulated Marketing
LSD.05=

Table 9. Bud number from vernalized *L.* 'Enchantment' lily bulbs given 0, 2, or 4 weeks of simulated marketing at 20C following storage at -2C.

Treatment Period	Bud Number
0 weeks	10.3
2 weeks	8.3
4 weeks	6.3

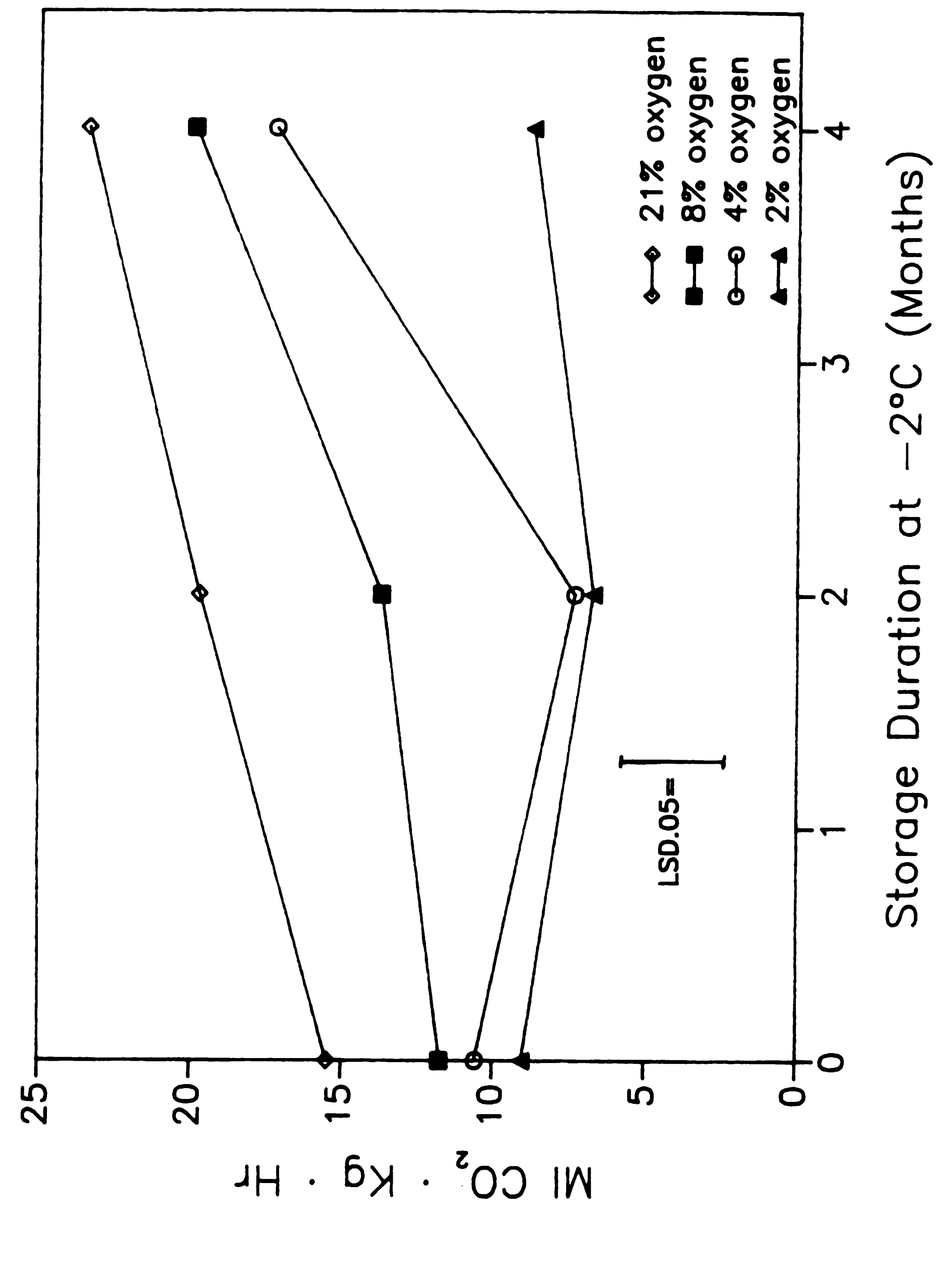
Note: $LSD_{.05}$ = 0.4 (for 2 & 4 week data only)

Table 10. Abscission rate during forcing of vernalized *L.* 'Enchantment' lily bulbs given 2 or 4 weeks of simulated marketing at 20C following -2C storage for up to 4 months.

Storage Duration (Months)	Treatment Period: 2 weeks				4 Weeks				Months While In Bloom
	Percent Oxygen								
	2	4	8	21	2	4	8	21	
0	0	0	0	0	0	2	0	0	March-April
1	0	0	0	0	0	0	0	0	April-May
2	0	0	0	0	0	0	4	23	May-June
3	0	0	0	0	0	0	0	40	June-July
4	0	0	0	0	0	0	7	0	July-August

Note: $LSD_{.05}$ = 10.7

Fig. 5. Respiration rate of vernalized _L._ 'Enchantment' lily bulbs held at various low oxygen levels or in air for up to 4 weeks (at 20C) following cold storage (-2C) for up to 4 months. Values are averages of measurements taken every 2 to 3 days.



Ml CO2 · Kg · Hr
25
20
15
10
5
0
0
1
2
3
4
Storage Duration at −2°C (Months)
LSD.05=
21% oxygen
8% oxygen
4% oxygen
2% oxygen

The respiration rate also increased with increasing levels of oxygen (Fig. 5). Average respiration rate at 21% O_2 was nearly 2.5 times higher than the average rate at 2% O_2.

DISCUSSION

Postharvest storage and handling methods for Lilium 'Enchantment' lily bulbs commonly involve prolonged storage at -2C after 6 weeks vernalization (2.5C) prior to the marketing period. Cold-stored bulbs moved to 20C begin shoot elongation whether they are in a pot with soil and water or setting on a store shelf. The delicately slender shoot is easily broken off which prevents flowering. A refrigerated display would retard shoot elongation, but is not considered an economically viable solution at this time. A low oxygen atmosphere established within a polyethylene film package has been shown to decrease respiration rate and maintain future flowering potential of tulip bulbs (29).

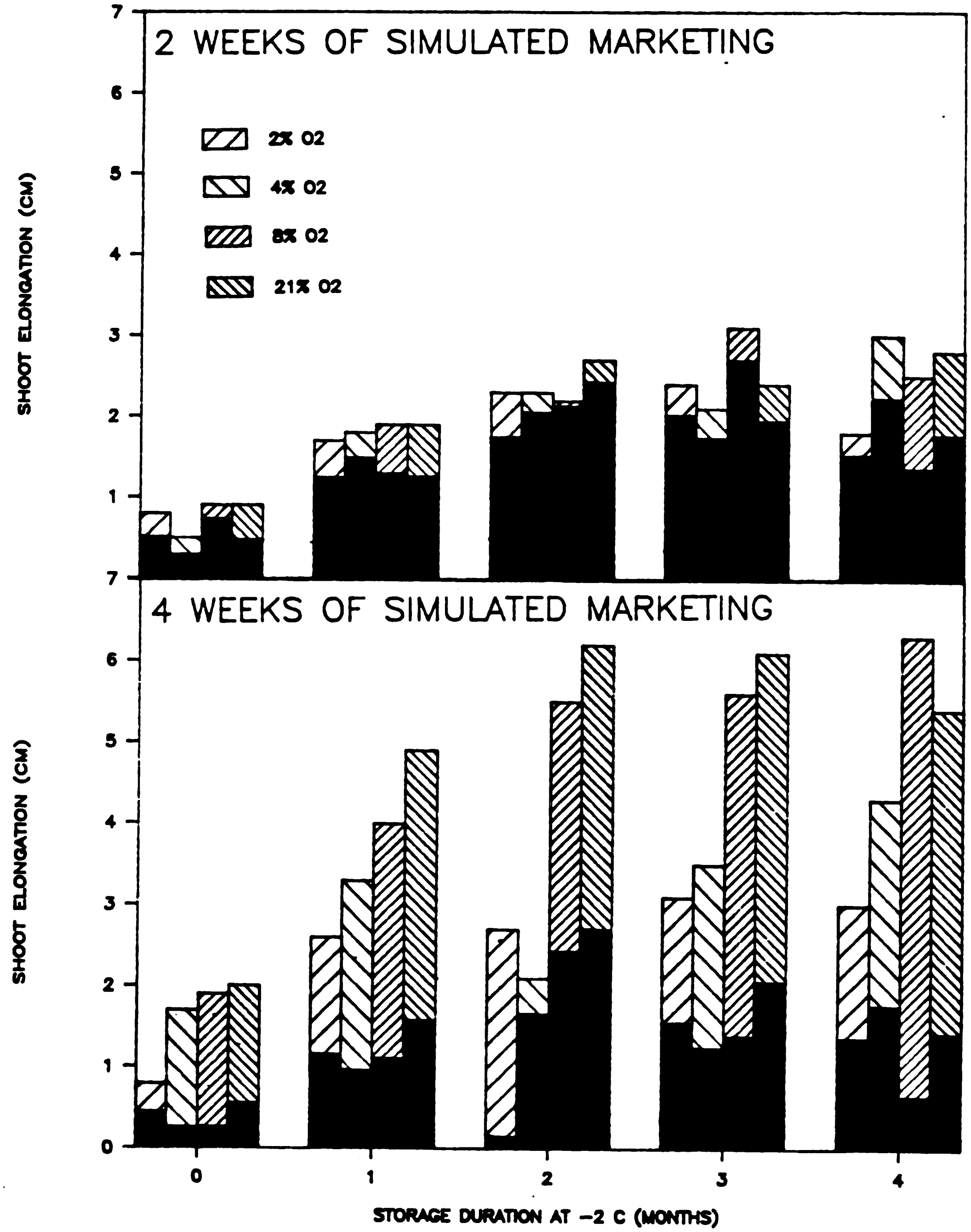
We found that 2% O_2 levels around bulbs in a continuous air-flow system simulating the marketing period did retard shoot elongation of Enchantment lily bulbs (Fig. 1). The average shoot elongation in bulbs held for 4 weeks at 2% O_2 (1.0cm), regardless of -2C storage duration, would not present a problem during marketing. Average shoot elongation in bulbs held 4 weeks in air (3.2cm) is more than three times as much as that observed in 2% O_2 and a stem this length could easily be damaged during retail display.

Even though 2% O_2 successfully retarded shoot elongation during the simulated marketing period, shoot elongation during storage accounted for nearly two-thirds of total shoot elongation (Fig. 6). Combined average shoot elongation of bulbs held for 4 weeks at 2% O_2 after receiving at least one month of -2C storage was 2.9 cm which, as stated above, could easily be broken off. Thus, consideration needs to be paid to optimizing storage conditions, creating an environment humid enough to keep the fleshy storage roots from desiccation, but dry enough to inhibit shoot elongation. Perhaps low oxygen during -2C storage would solve this problem.

Progressively longer cold storage resulted in greater shoot elongation during the simulated marketing period and an increasing respiration rate (Figs. 1 & 5). Adamicki's research on onions (1) showed that respiration rate increased more upon transfer to 10C when the onions had been stored at lower temperatures (1C & 5C) as compared to storage at 10C and 15C. This corroborated Ward (39) who reported that onion bulbs transferred from 2C to 25C showed a higher respiration rate than of those stored continuously at 25C.

Many researchers have investigated the positive and negative effects of low temperature storage and

Fig. 6. Shoot elongation during cold storage at -2C (blackened lower sections) and during the subsequent simulated marketing period when bulbs were held at varying oxygen levels for 2 weeks (top graph) or 4 weeks (bottom graph) at 20C. O_2 levels during cold storage were not experimentally varied, although variations may have occurred due to physiological changes within bulbs.


2 WEEKS OF SIMULATED MARKETING
2% O2
4% O2
8% O2
21% O2
SHOOT ELONGATION (CM)
4 WEEKS OF SIMULATED MARKETING
SHOOT ELONGATION (CM)
0
1
2
3
4
5
6
7
STORAGE DURATION AT -2 C (MONTHS)

poststorage modified atmospheric treatment on the subsequent flower quality of Easter lily bulbs (3,4,7,8,9,13,14,15,16,17,22,23,24,25,26,30,31,32,33,34, 37). The present study on Enchantment lily bulbs generally supports earlier work with Easter lilies which concluded that both storage techniques represent trade-offs. Although both low temperature storage and low oxygen treatment expand the time period when bulbs can be marketed, they can cause a significant decrease in overall plant quality. In general, a plant from a lily bulb which has come out of cold storage will bloom faster and be shorter (favorable consequences for a pot plant), but the plant will also have fewer flowers with shorter inflorescence duration, an unattractive stem pattern (shrunken lower internodes with a bare stem section below the flower) and frequently a higher rate of bud abscission.

Subjecting vernalized bulbs first kept in -2C storage to a low O_2 or air environment for up to a month prior to forcing only further enhances most of the adverse results of cold storage mentioned above (36).

Enchantment lily bulbs brought out of cold storage and kept in air (and 4 and 8% O_2 to a lesser extent) at room temperature experienced a stimulation in respiration rate and enhanced shoot elongation. After 4 weeks in this environment, they were presumably undergoing normal physiological processes towards the goal of flowering. However, since they were not in an environment conducive to normal growth and development, subsequent flower quality was greatly reduced.

The 2% oxygen atmosphere reduced the bulbs' physiological processes as measured by respiration and shoot elongation and enhanced subsequent flower quality compared to bulbs held in air. Langhans and Weiler (22) speculated that low O_2 might devernalize bulbs and thus delay floral initiation. Durkin and Hill (14) stated that delayed flowering may allow for the development of a more vigorous plant and a greater capacity for floral initiation.

Bulbs given air for 2 or 4 weeks following -2C storage bloomed more quickly than those held in 2% O_2, but the latter had less shoot elongation and were of superior quality in terms of the several flowering characteristics studied. A bulb given 4 weeks of air at 20C averaged over cold storage duration, bloomed in almost half the time (a month sooner) than a bulb given no cold storage or poststorage treatment (see Fig. 7). This occurrence could have favorable implications since the time until blooming for Enchantment lilies is relatively long for a pot plant. Thirty-nine days until flowering (Fig. 3) is still nearly twice the time it takes many tulip cultivars sold currently for pot plant

Fig. 7. Difference in maturation of vernalized 'Enchantment' lily bulbs held at -2°C for one month followed by 4 weeks of low O_2 treatment prior to forcing. Plants are 46 days from potting on 2-28-85.


-2°C → 1 month
+
20°C → 4 weeks
Light
2% O2
4% O2

production (3 weeks). The drawback to more rapid flowering is that quality is sacrificed for speed.

Loss in plant quality occurred during both cold storage and poststorage treatment period. Bulbs which received 2% O_2 treatment had somewhat higher quality floral characteristics, but it appears that keeping bulbs at 20C, particularly after storage at -2C, is the main factor in lowering regrowth potential. When Stuart (36) treated vernalized 'Ace' lily bulbs to a 2 week 21C treatment prior to or following vernalization, he found that the latter treatment accelerated flowering. Accelerated flowering generally implies decreased quality in bud number, inflorescence duration, etc. Low O_2 appears to have inhibited some of the adverse effects of holding bulbs at 20C for up to 4 weeks.

In all cases, 2% oxygen did not prevent adverse effects. No matter what the level of oxygen, there was significant decrease in the length of the inflorescence duration when poststorage treatment was given (Table 5).

For the most part as oxygen level increased, so did shoot elongation in bulbs held for 4 weeks. No clear trend can be observed for stem height which may indicate that this factor was influenced by more than cold storage and simulated marketing than by O_2 levels. Noordegraaf's studies (26) on 2 other lily cultivars show that stem length is strongly influenced by temperature during forcing with a lower temperature giving longer stems. He found that light also has an effect. Durieux (13) recommends installing supplementary lighting 150cm above the plants to prevent bud abscission. Since the lights that we used were permanently affixed in height while plants grew and stem height varied from plant to plant, not all the plants were 150cm below the lights. From bud stage forward, most plants could have been close enough to the lights to affect flowering. Although nonflowering plants were usually kept on an adjacent bench, they were still affected by the light. This was evidenced by a tendency of nearby plant stems not directly under the lights to grow toward the light source.

Height control of potted lilies is essential. Prolonged cold storage, poststorage treatment, heat and supplemental lighting may all decrease height. All or many of these factors are utilized commercially and may cause extreme stunting as well as unfavorable changes in stem habit.

Although we could detect no measurable levels of ethylene from gas samples taken during the simulated marketing period, the effects of stem habit and height may have been due in part to ethylene (data not shown). Previous tulip bulb research in the Netherlands (10) found that low concentrations of ethylene (0.05 to 10

μl^{-1}) produced varying degrees of inhibition of shoot elongation as well as inhibiting growth of roots, leaves and flowers after planting. Kamerbeek and Durieux (unpublished; 18) found that the elongation of the stem internodes of lilies is temporarily stopped by the presence of ethylene. Dicks and Rees (12) observed a considerable reduction of stem height by ethephon of mid-century hybrid lilies.

Bud number was greatly affected by -2C storage and simulated marketing (Fig. 4). There was no significant difference between oxygen levels which probably indicates that it was the timespan itself at room temperature following cold storage which had adverse effects on the number of buds. Two percent oxygen did not seem to influence the physiological processes within the bulb which affect bud number.

Stuart (34) reports that as storage duration lengthens up to 8 months, bud number of Easter lily decreases. Our results did not confirm this with 'Enchantment' lilies. In the current study, bud number fell by one-third (10 down to 7) after one month of -2C storage and then remained at nearly that number for up to 4 months of cold storage (Fig. 4).

No bud abscission occurred at the 2% O_2 level, even after 4 weeks of treatment (Table 11). As oxygen level increased, so did abscission. Kamerbeek (17) showed that the longer the storage at 2C, the higher the percentage of nonabscissed buds. Our results showed a significant difference in bud abscission with varying -2C storage durations, but it should be noted that the highest rates of abscission (3.4% and 5.0%) occurred in plants forced in June and July when greenhouse temperatures were high. Kohl (20) and Durieux (13) state that higher temperatures in the greenhouse promote the occurrence of abscission, especially when applied during the wrong stage of development. Perhaps there was an interaction of 21% O_2 levels with high temperatures in that these bulbs were at a physiological stage receptive to damage by high temperatures while bulbs held in 2% O_2 were not. All plants held for 4 months of cold storage had a low average rate of abscission (less than 1.0%).

Our results indicate that holding bulbs in air at 20C for 4 weeks significantly increased bud abscission. For those bulbs given no poststorage treatment, but planted directly following 0, 1, 2, 3, or 4 months cold storage there was no bud abscission. Nor was there after two weeks of simulated marketing at any oxygen level. Bud abscission only occurred on plants which had been held for 4 weeks at 20C in 8% or 21% O_2 after 2 or 3 months of cold storage, but not, surprisingly, after 4 months.

Optimally, Enchantment lilies should not be forced above 21C (11). The higher greenhouse temperatures which occurred during the summer months may also have affected bud number (20,27) and stem height (20) as well as bud abscission rate (27).

Bulbs were given 2 or 4 weeks of simulated marketing to determine the limit to which bulbs can be held without loss in quality. Our results indicated that in nearly every case, the 4 week treatment period adversely affected flower quality to a greater degree than 2 weeks which, in turn, was usually worse than the controls receiving no simulated marketing treatment. In many cases the 2 week bulbs were not visually much different in quality than the controls while the 4 week bulbs were obviously of inferior quality to the controls (Fig. 7).

Bulbs held in 2% O_2 had one-third the shoot elongation of those given 21% O_2 (1.0 cm to 3.2 cm). While low oxygen treatment did show some success in this area, it did not satisfactorily prevent undesirable reduction in flower quality. In terms of visual comparison of two plants, one whose bulb was held in 2% O_2 for 4 weeks and one in 21%, the differences may not be enough to convince the consumer to buy the former.

At the present time, refrigeration in polyethylene bags surrounded by peat moss is still the best means available for marketing of Enchantment lily bulbs.

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SECTION 2:

MODIFIED ATMOSPHERIC PACKAGING OF VERNALIZED *LILIUM* 'ENCHANTMENT' LILY BULBS: A PRELIMINARY STUDY

INTRODUCTION

Controlled atmosphere (CA) and modified atmosphere (MA) storage has proven successful in extending the shelf life of many horticultural commodities (5,13,14,20,22, 27). The earliest research was thought to show that film wrapping was not feasible for the most part unless the film was perforated (1,12,21,23). The problem with much of the work done up to a few years ago is that it was performed without optimizing parameters, such as film permeability, package size, weight of commodity, respiration rate, and the optimal O_2 concentration for storage, etc.

Prince (20) developed a modified atmosphere packaging system for storing precooled tulip bulbs. At equilibrium the gas concentrations within the low-density polyethylene (LDP) packages of 5 bulbs each were 5% O_2 and 4% CO_2. These concentrations, as well as package type and size, had been determined beforehand to be within the optimal range. Excellent flowering was obtained upon forcing after 4 weeks of storage.

One of the few studies done on the effects of low oxygen on lily bulbs was done by Thornton in 1941 (26). He found that low O_2, coupled with high CO_2 (40%), inhibited shoot elongation. Our results shown in Sec. 1 suggest that low O_2, together with moderately high levels of CO_2, inhibited shoot elongation of vernalized Enchantment lilies. A later study (2) showed that gas levels within polyethylene film bags containing peat moss and 7 inch Ace and Croft lily bulbs held at 21C equilibrated at 4% O_2 and 10% CO_2. (No detailed information on the type of film used was given in this study.) Gas levels remained steady for the entire 6 week storage period. When regrowth potential was compared to the nonstored control plants, bulbs stored at 21C for 6 weeks flowered much earlier, but had fewer leaves and fewer flowers than the controls (2).

The following preliminary study on Enchantment lily bulbs was done to test the polyethylene film used successfully to package tulip bulbs for 4 weeks (20). Since tulip and lily bulbs had similar respiration rates, it was thought that using the same film would provide a general comparison to the studies in Sec. 1 and yield preliminary data which could be utilized for future optimization of a packaging system for Enchantment lily bulbs.

MATERIALS AND METHODS

Plant Material

Lily bulbs of the cultivar Lilium 'Enchantment' (12.5-15 cm in circum.) were harvested around October 8, 1984, in Sandy, Oregon, and shipped to East Lansing, Michigan, on October 12, 1984. The bulbs arrived eight days later. The bulbs were reported to have received about 10 days storage at 4.5C by their arrival time.

After arrival, all bulbs were held at 21C for two weeks. The bulbs were then vernalized at 2.5C for six weeks (6,7,24) before transfer to -2C (9).

Throughout vernalization and storage, bulbs remained packed as they were shipped, in moist peat moss (averaging 60% moisture content: data not shown) within polyethylene liner bags.

Treatment Application

Bulbs were removed from cold storage (-2C) in August, 1985, after 260 days of storage. They were left covered with plastic on the laboratory bench for 24 hours at room temperature to equilibrate.

Bags (20 x 20 cm, top and bottom) were fashioned from LDF-301 low-density polyethylene film (Dow Chemical Co.) (20). The film's thickness was 0.051 mm and permeability to CO_2 and O_2 was 16.43 and 4.17 l atm-1 day-1 m-2, respectively. Half the bags were punched with five 4 mm holes. In Experiment A a control treatment of bulbs in onion mesh bags was added. This was not repeated during Experiment B.

Experiment A

Two or four bulbs were placed into each bag and each bulb was identified by a labeled tag gently tied onto the root section. Measurement of shoot elongation prior to treatment was noted. The bags were then heat sealed and the entire package with bulbs was weighed. Sealed bags were outfitted with a sampling port, according to the method described by Boylan-Pett (5).

The bags were kept in an unlit room at 21C. Gas samples (1 cc) were taken every 2-3 days for 4 weeks for analysis of the carbon dioxide and oxygen levels.

Analysis of the gas samples was performed on a Carle 8700 gas chromatograph employing a thermal conductivity detector and equipped with two columns in series. One column was of silica gel for separation of nitrogen and oxygen using helium as the carrier gas at 70C (19).

Each week (4 times total) bags containing bulbs were weighed and individual shoot elongation measured with a ruler as accurately as possible through the bags. Final shoot length was measured after bulbs were removed from the bags prior to forcing.

Experiment B

The first portion of the experiment was conducted similar to Experiment A.

A set of 16 control bulbs which had not been packaged were planted in the greenhouse at the start of the experiment. At 2 and 4 weeks, bulbs from one set of bags were planted in the greenhouse in either 12.5 or 15 cm clay pots using a peat-perlite mix. When bud length reached approximately 2 cm potted plants were placed under high intensity lights continuously (24 hours) (3,4,10,28).

Data were taken on several flower quality characteristics: (1) the number of days from planting until the first fully expanded flower; (2) the inflorescence duration measured as the number of days from the first fully expanded flower until petal-fall from the final blooming flower; (3) total stem height as measured from the soil surface to the point of pedicel origin; (4) the length of the lower stem section with foliage; (5) the length of the upper stem section immediately below pedicel origin which may be free of foliage; (6) total number of buds; (7) percent bud abscission; and (8) flower size as measured by the length times the width (cm) of one lower petal.

RESULTS

Gas Levels

Oxygen levels within sealed bags and bags with holes containing 2 or 4 bulbs are shown in Fig. 1. The level of O_2 equilibrated at 7.3% and 4.7% within sealed bags containing 2 or 4 bulbs, respectively. CO_2 levels rose within sealed bags to an average of 7.1% with a mean high of 8.8% in sealed packages of 4 bulbs (Fig. 1).

Shoot Elongation

Average shoot elongation of bulbs in both types of bags did not differ significantly from each other.

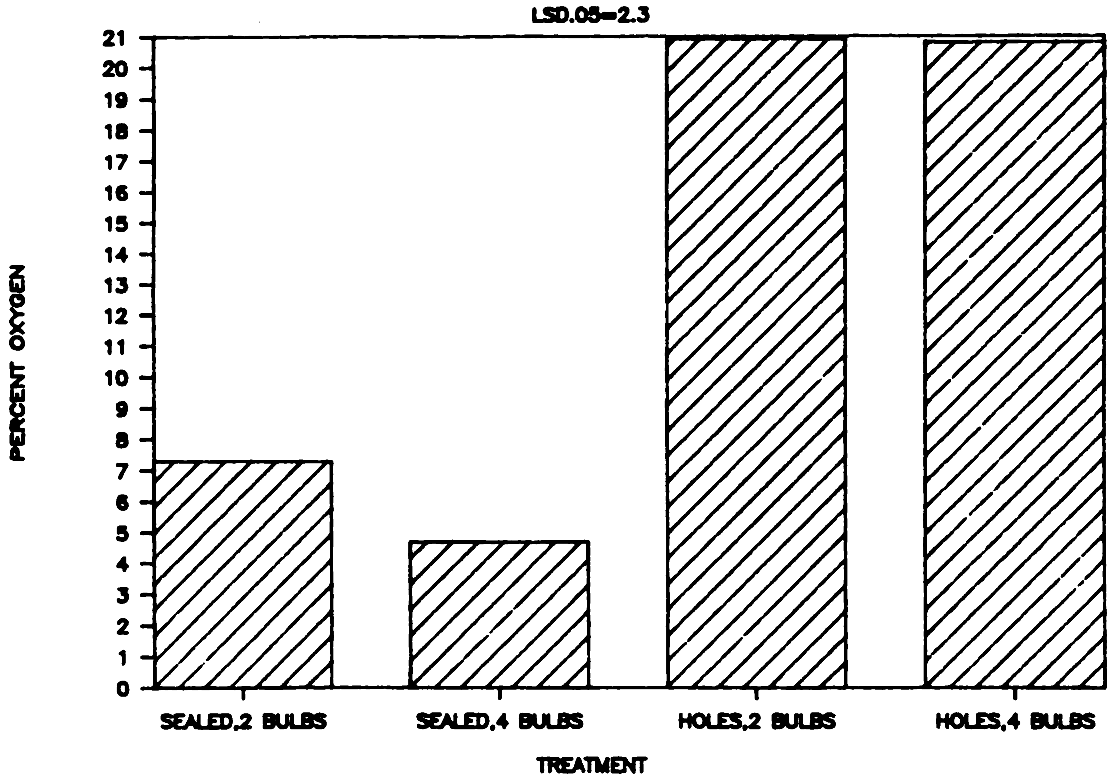
Water Loss

Bulbs in sealed bags, whether 2 or 4 bulbs per bag, lost only an average of 2.7% of their weight or one-tenth that lost by bulbs in bags with holes (26.1% average) (Fig. 2).

Days to First Flower

The least number of days until first flower occurred in bulbs held for 4 weeks in bags with holes (35 days) (Fig. 3). This was an average of 10 days earlier than the number of days until first flower of bulbs kept in

Fig. 1. Percent oxygen (top graph) and percent carbon dioxide (bottom graph) within polyethylene bags, sealed or with holes, containing 2 or 4 vernalized lily bulbs (cv. *L.* 'Enchantment') for up to 4 weeks at 20C. Prior to packaging bulbs had been stored at -2C for 9 months.


LSD.05=2.3
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
PERCENT OXYGEN
SEALED,2 BULBS
SEALED,4 BULBS
HOLES,2 BULBS
HOLES,4 BULBS
TREATMENT

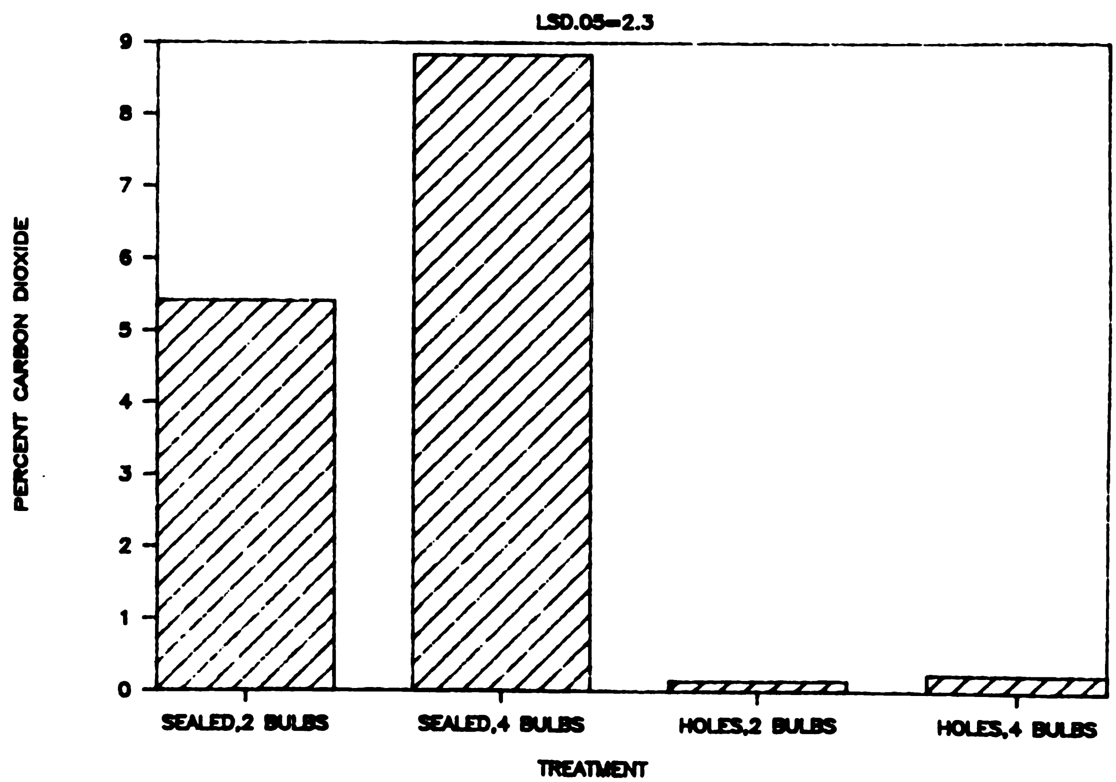

LSD.05=2.3
9
8
7
6
5
4
3
2
1
0
PERCENT CARBON DIOXIDE
SEALED,2 BULBS
SEALED,4 BULBS
HOLES,2 BULBS
HOLES,4 BULBS
TREATMENT

Fig. 2. Total percent water loss from vernalized lily bulbs (cv. _L._ 'Enchantment') while kept in polyethylene bags, sealed or with holes, containing 2 or 4 bulbs for up to 4 weeks at 20C. Prior to packaging bulbs had been stored for 9 months at -2C.

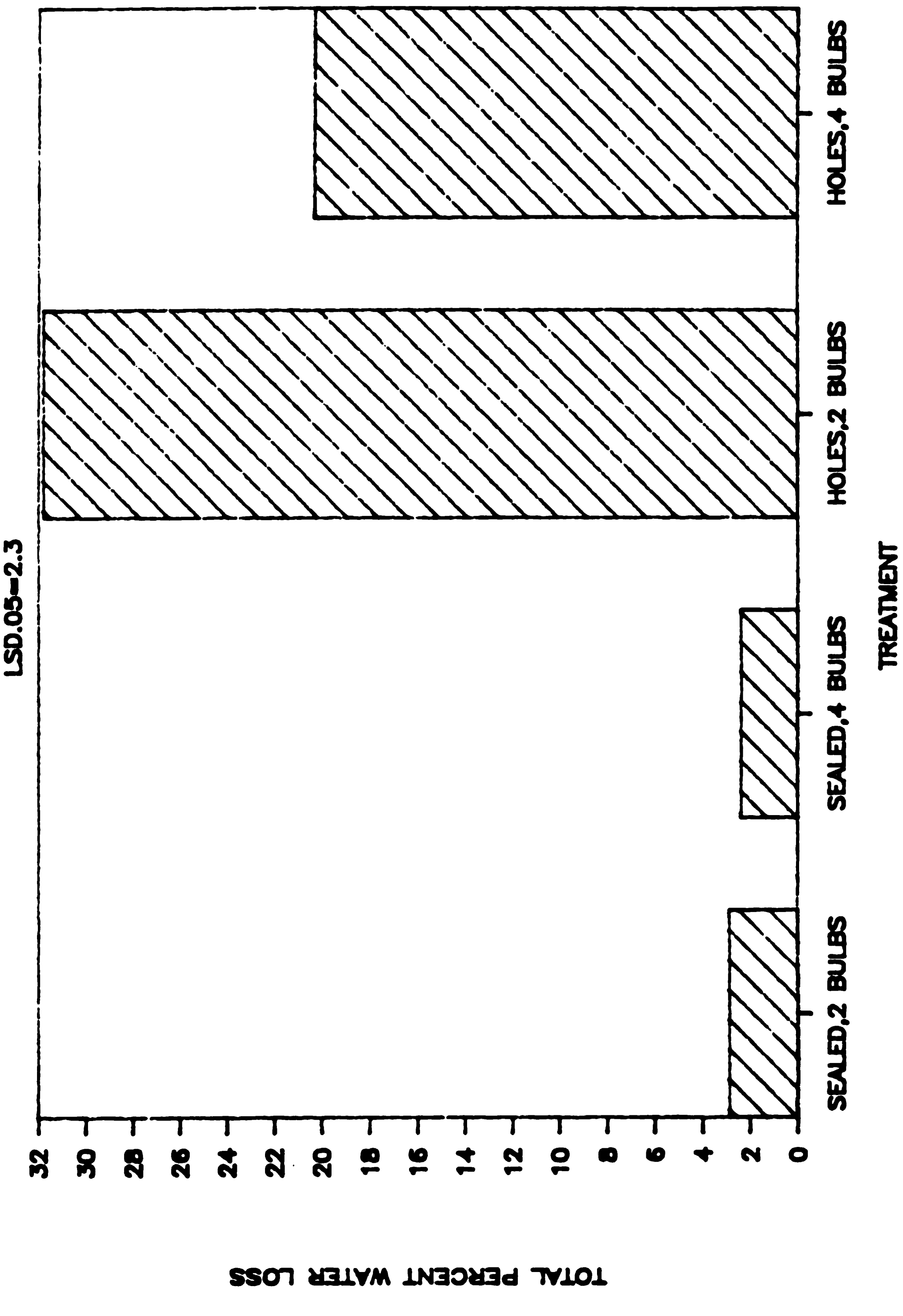
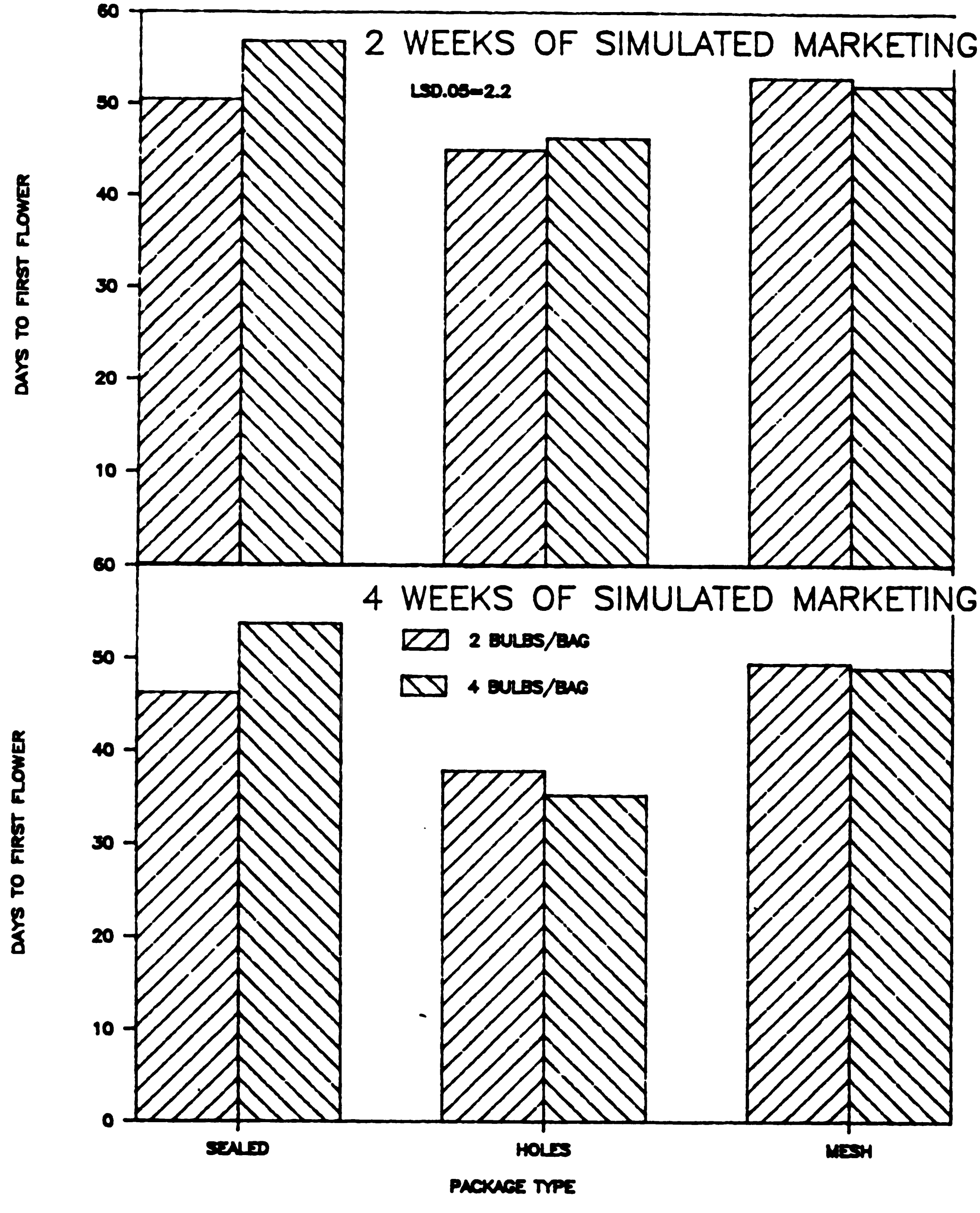

LSD.05=2.3
TOTAL PERCENT WATER LOSS
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
SEALED,2 BULBS
SEALED,4 BULBS
HOLES,2 BULBS
HOLES,4 BULBS
TREATMENT

Fig. 3. Days to first flower of vernalized L. 'Enchantment' lily bulbs after packaging for 2 weeks (top graph) or 4 weeks (bottom graph) in polyethylene bags, sealed or with holes or onion mesh bags with 2 or 4 bulbs each at 20C. Prior to packaging bulbs had been stored at -2C for 9 months.


2 WEEKS OF SIMULATED MARKETING
LSD.05=2.2
4 WEEKS OF SIMULATED MARKETING
2 BULBS/BAG
4 BULBS/BAG
DAYS TO FIRST FLOWER
DAYS TO FIRST FLOWER
0
10
20
30
40
50
60
SEALED
HOLES
MESH
PACKAGE TYPE

sealed or mesh bags, regardless of time in bags (52 and 50 days, respectively). This was also more than 3 weeks earlier than the controls (58 days). Bulbs packaged for 2 weeks bloomed on an average of 6 days later than bulbs packaged for 4 weeks, regardless of package type (51 and 45 days, respectively).

Inflorescence Duration

Bulbs held in either sealed or mesh bags for 2 weeks bloomed for a longer period than bulbs kept in either bag type for 4 weeks (nearly 3 days longer) (Fig. 4). Bulbs kept up to 4 weeks in bags with holes had the same inflorescence duration as the controls (nearly 14 days) (Fig. 4).

Stem Height

As the number of weeks in the bags increased, stem height decreased (Table 1). Bags with holes containing 2 bulbs yielded taller plants than bags with 4 bulbs (Fig. 5).

The average stem height of bulbs kept in bags for up to 4 weeks was 30 cm while controls averaged 34 cm.

Bud Number

Bud number was highest among bulbs kept in bags with holes, particularly with 4 bulbs per bag (Fig. 6). Control bulbs yielded an average bud number of 10.1 while

Fig. 4. Inflorescence duration of vernalized *L.* 'Enchantment' lily bulbs which had been packaged in polyethylene bags, sealed or with holes, or onion mesh bags each containing 2 or 4 bulbs for 2 and 4 weeks following 9 months storage at -2C.

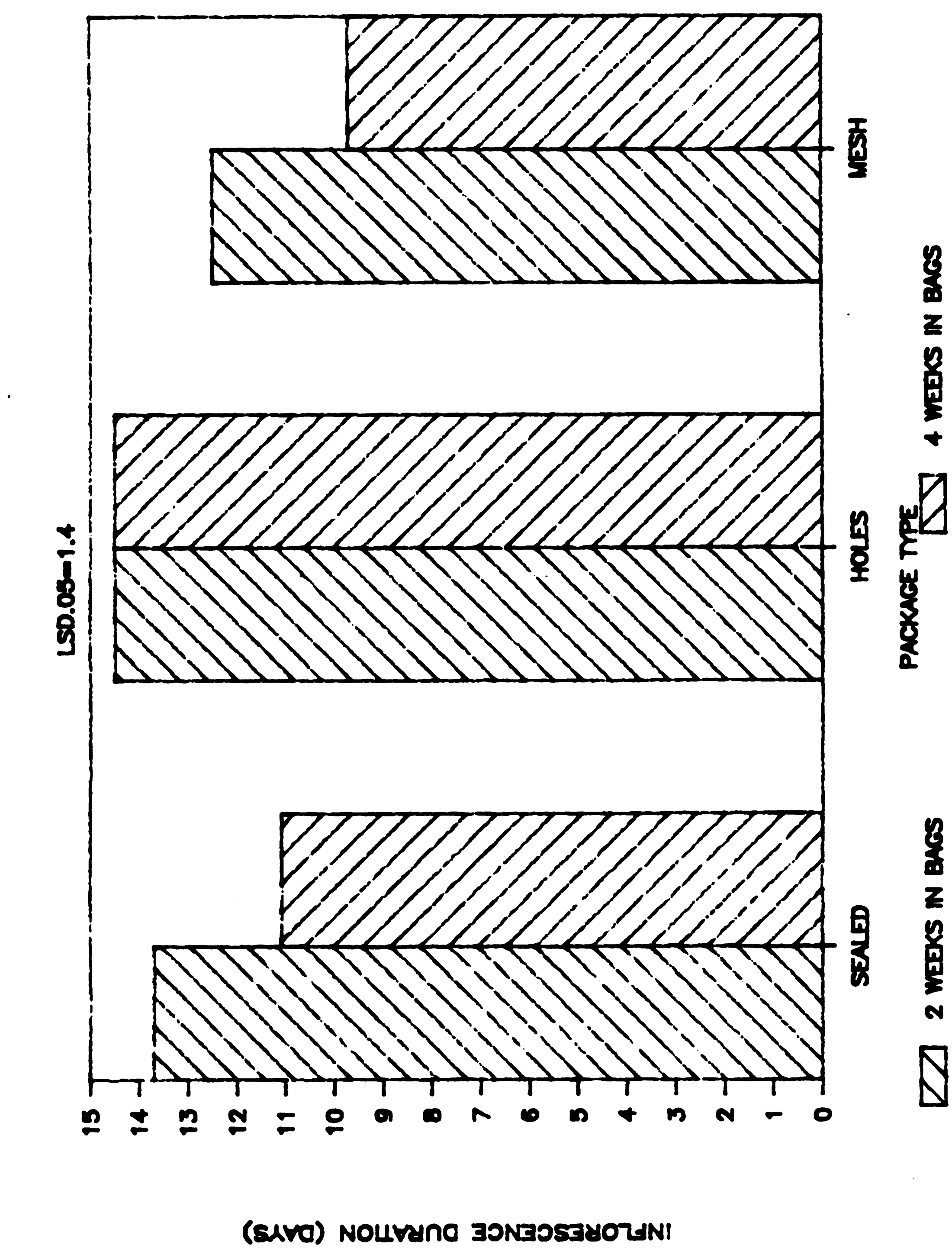

LSD.05=1.4
INFLORESCENCE DURATION (DAYS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
SEALED
HOLES
MESH
PACKAGE TYPE
2 WEEKS IN BAGS
4 WEEKS IN BAGS

Table 1: Stem height of vernalized *L.* 'Enchantment' bulbs held 2 or 4 weeks in 3 types of packages: sealed polyethylene, polyethylene with holes and onion mesh, prior to forcing.

Weeks in Bags	Stem Height (cm)
0	34.0
2	33.2
4	26.3

Note. LSD.05 = 1.7 for 2 and 4 week data only.

Fig. 5. Stem height of vernalized *L*. 'Enchantment' lily bulbs which had been packaged in polyethylene bags, sealed or with holes, or in onion mesh bags each containing 2 or 4 bulbs for up to 4 weeks following 9 months storage at -2C.

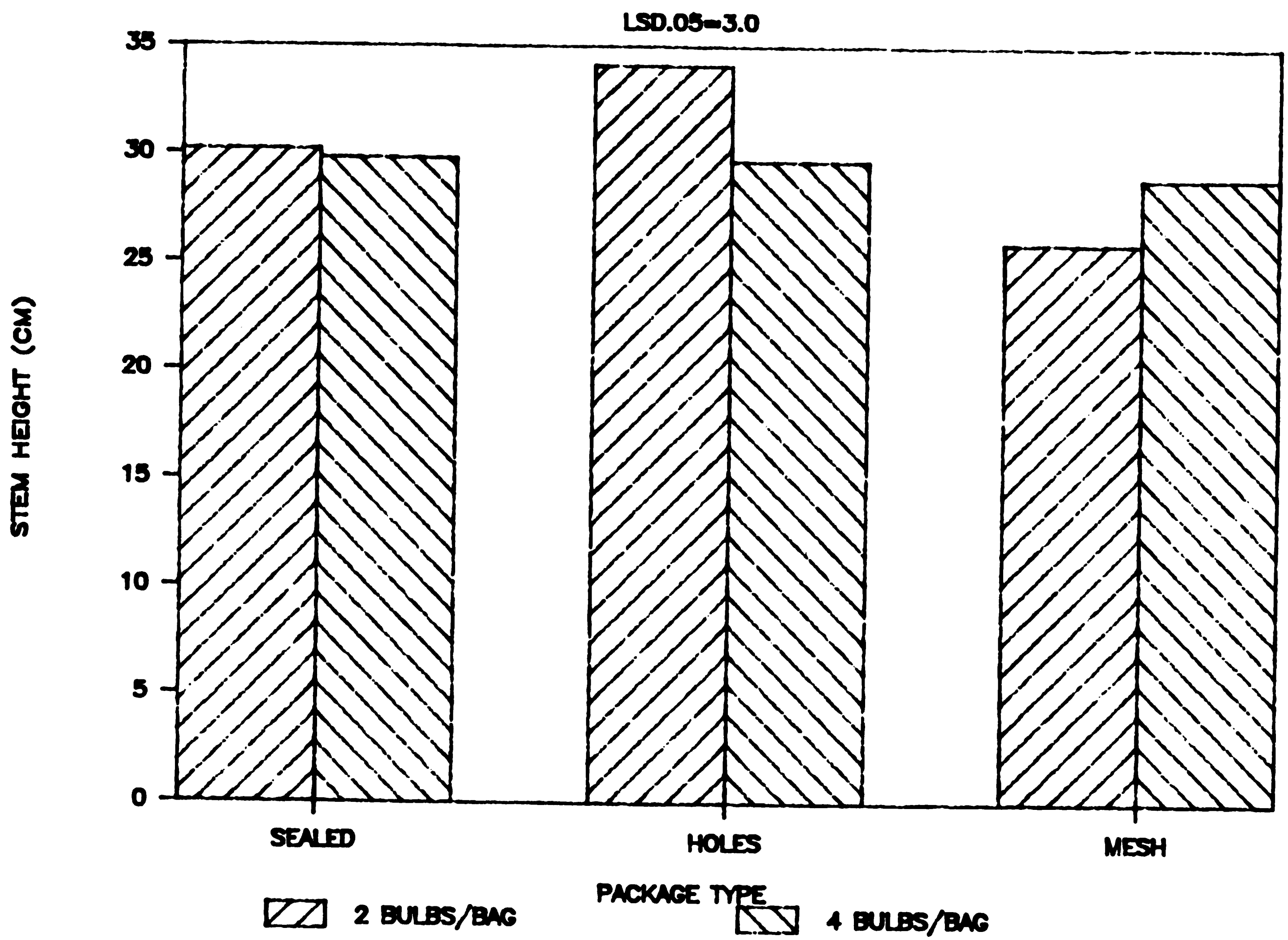
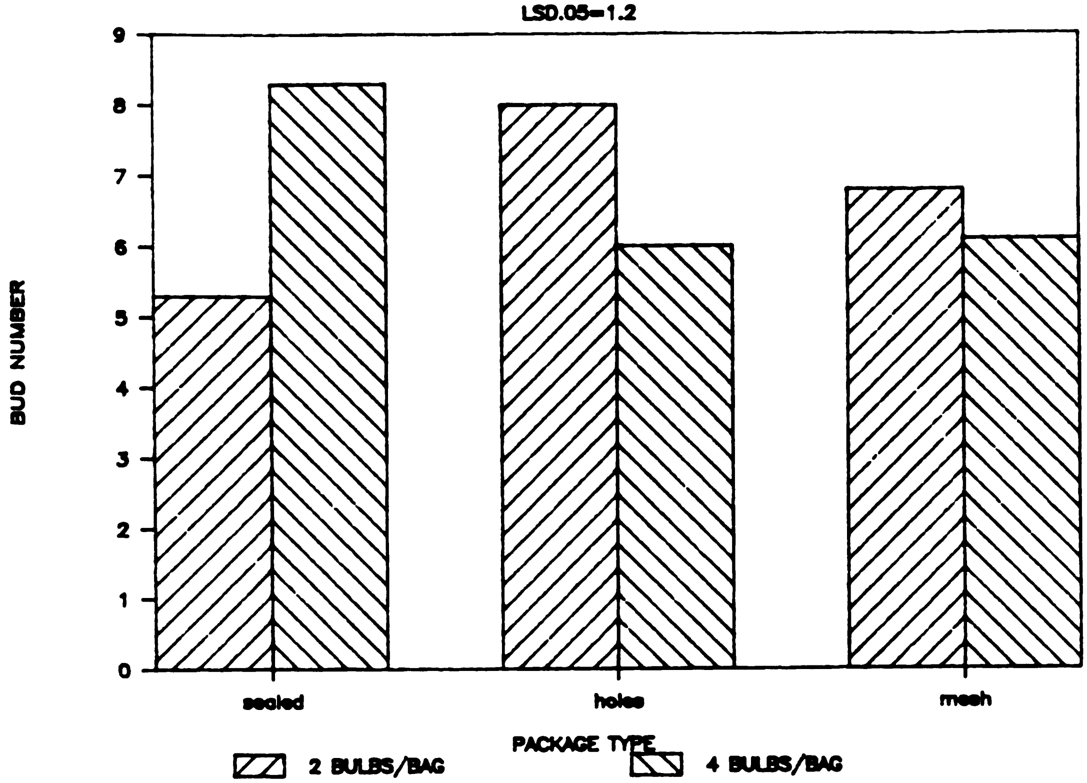
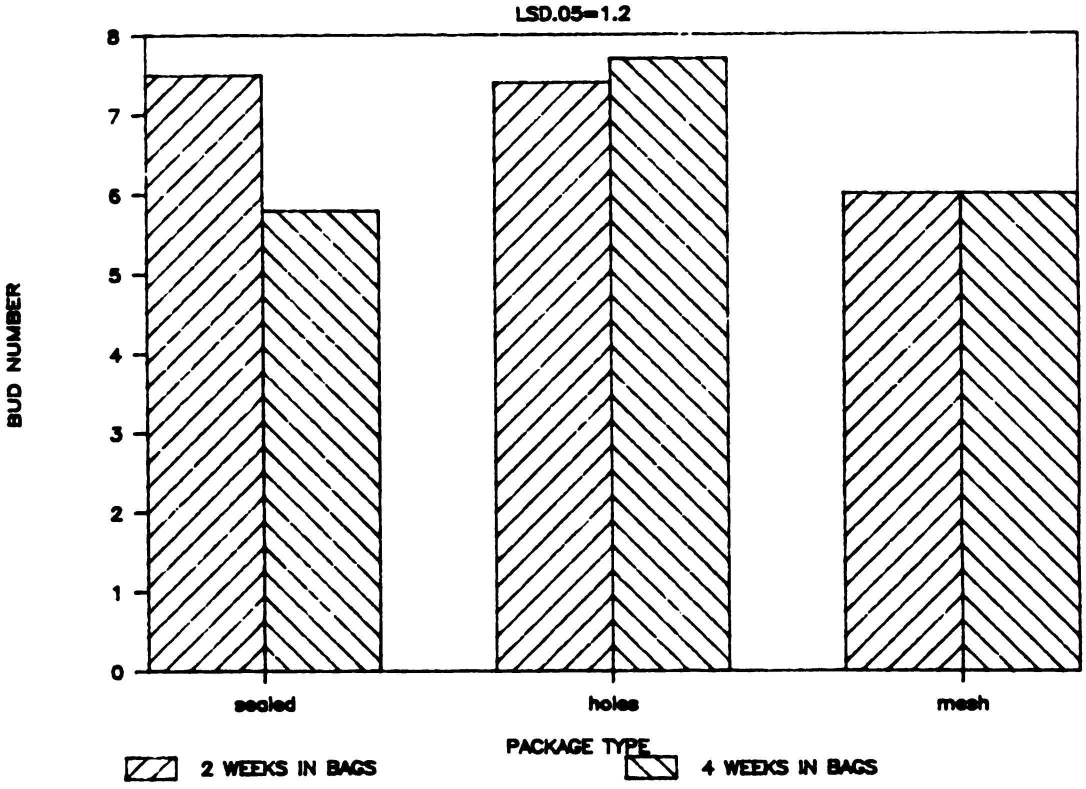

LSD.05=3.0
STEM HEIGHT (CM)
35
30
25
20
15
10
5
0
SEALED
HOLES
MESH
PACKAGE TYPE
2 BULBS/BAG
4 BULBS/BAG

Fig. 6. Bud number of vernalized *L.* 'Enchantment' lily bulbs which had been packaged in polyethylene bags, sealed or with holes, or in onion mesh bags each containing 2 or 4 bulbs for 2 weeks (top graph) or 4 weeks (bottom graph) following 9 months storage at -2C.


LSD.05=1.2
BUD NUMBER
0
1
2
3
4
5
6
7
8
9
sealed
holes
mesh
PACKAGE TYPE
2 BULBS/BAG
4 BULBS/BAG


LSD.05=1.2
BUD NUMBER
0
1
2
3
4
5
6
7
8
sealed
holes
mesh
PACKAGE TYPE
2 WEEKS IN BAGS
4 WEEKS IN BAGS

the average for all bulbs kept in bags for up to 4 weeks was 6.7, a decrease of one-third.

Petal Size

The largest flowers resulted when bulbs were kept in bags with holes while the smallest were from bulbs kept in sealed bags. Petal size decreased as weeks in bags increased and with increasing number of bulbs in bags (Tables 2 and 3). Average petal size of all bulbs kept in bags was actually slightly larger (121.5 cm) than the controls (118.4 cm).

Table 2: Petal size (length x width of 1 petal) of vernalized *L.* 'Enchantment' bulbs held 2 or 4 weeks in 3 types of packages: sealed polyethylene, polyethylene with holes and onion mesh, prior to forcing.

Weeks in Bags	Petal Size (cm)
2	123.8
4	119.8

Note: LSD.05 = 2.4

Table 3: Petal size (length x width of 1 petal) of vernalized *L.* 'Enchantment' bulbs held up 4 weeks in various packages containing 2 or 4 bulbs prior to forcing.

Bulb Number	Petal Size (cm)
2	123.0
4	119.9

Note: LSD.05 = 2.4

DISCUSSION

Oxygen levels inside sealed bags did fall within levels studied in Sec. 1 (2, 4, & 8% O_2). The wide range of oxygen levels we obtained could have been due in part to the advanced age and condition of the bulbs which may have increased variability.

We could not tell with certainty if the CO_2 levels which were obtained from sealed bags had toxic effects on bulbs as Thornton found in his research (26). Thornton reported a retardation in shoot emergence and in growth and flowering of the plants produced when bulbs were held in 40% CO_2. Although our highest average levels of CO_2 were only about 9%, it is probable that these levels could have caused the same adverse effects as Thornton observed.

Several regrowth quality characteristics for bulbs held in bags with holes were surprisingly superior to bulbs in sealed bags. However, several factors appeared to have an adverse effect on regrowth potential, such as storage at -2C and holding bulbs at 20C regardless of oxygen level. These factors appear to interact together in lowering regrowth potential.

As mentioned earlier, bulbs kept in bags with holes had surprisingly better regrowth potential in several instances as compared to bulbs kept in sealed bags. Bulbs from bags with holes on the average flowered 10 days earlier than sealed or mesh bags, but had one more bud, an inflorescence lasting 3 days longer and larger flowers. This is contrary to the results obtained and conclusions made from the experiments in Sec. 1 and from most previous research (6,7,11,17). In previous cases, more rapid flowering is associated with decreased flower quality. One study does corroborate these results. Miller and Kiplinger (18) conducted a study on Enchantment lily bulbs testing the hypothesis that a period of nonvernalizing temperatures prior to vernalization would seem desirable. Their most striking finding showed that plants exposed to temperatures promoting most rapid flowering had greater numbers of flowers.

Research done by Boylan-Pett (5) showed that a miniscule hole in a polymeric film package was sufficient to change radically the internal gas levels. Our 4 mm holes were apparently too large as evidenced by the large water loss.

A possibility for lily bulbs currently being investigated on tulip bulbs is the packaging of bulbs in polyethylene film containing peat moss prior to vernalization and/or storage at -2C. Gradually the film shrinks tightly around the tulip bulbs and may, in the case of lily bulbs, provide a barrier to short elongation which also occurred during storage as well as during simulated marketing (A. Cameron-personal observation). Lowering the respiration rate may prevent some of the adverse effects of over-vernalization which occurs in bulbs stored for long periods of time at temperatures less than 20C.

Boylan-Pett (5) studied the effect of magnesium oxide on absorbance of CO_2 within sealed polyethylene film bags of tomatoes. Another area of future investigation might be in testing various carbon dioxide-absorbing chemicals in sealed film bags containing Enchantment lily bulbs and comparing flowering quality to bulbs kept in bags where CO_2 is allowed to accumulate naturally.

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SUMMARY

Our initial goal was to determine if a low oxygen level could inhibit shoot elongation of vernalized Enchantment lily bulbs during storage at room temperatures for up to a month without causing a loss in quality once forced.

The lowest O_2 level tested, 2%, was the only level effective in inhibiting shoot elongation within acceptable limits. However, 2% O_2 was not able to prevent or overcome the undesirable reduction in regrowth potential that resulted in all plants kept in low O_2 or air environments following storage at -2C and prior to forcing. Cold storage, itself, had a detrimental effect on regrowth potential and adverse effects were worsened by subsequent bulb storage at 20C, regardless of oxygen level.

Further studies on optimal MA packaging of lily bulbs should include ways to overcome some of the problems we encountered either due to our experimental approach or inherent to current commercial practices involving lily bulbs. Perhaps packaging bulbs immediately following vernalization or even at the time of harvest may offset some of the damage to regrowth potential in bulbs stored at -2C for many months It has been observed that gradually over time the polyethylene film package surrounding tulip bulbs shrinks closely against the bulbs (A. Cameron-personal observation). Perhaps this condition would provide a barrier to shoot elongation among vernalized Enchantment lily bulbs during storage and handling. Packaging bulbs prior to vernalization or cold storage would lower bulb respiration rate which might prevent some of the adverse effects that occur from over-vernalization after many months of storage at temperatures below 20C.

A means of preventing accumulation of toxic levels of carbon dioxide within sealed polyethylene film bags might be investigated. CO_2-absorbing chemicals, such as magnesium oxide, could be sealed within bags and be effective the entire marketing period.

As of now, refrigeration of Enchantment lily bulbs is still the best means by which to keep them during the marketing period.

APPENDIX

DEVERNALIZATION TREATMENT

Blaney et al. (2) and Hartley et al. (6) contend that temperatures of 21C and above given prior to vernalization preserve the flowering potential of Easter lily bulbs (L. longiflorum (Thunb) 'Ace'). Miller and Kiplinger (10) report that this same temperature range on 'Ace' lily bulbs has the effect of devernalization. Langhans and Weiler (8) state that temperatures of 21C and above can devernalize bulbs only if floral induction has not yet occurred. After the onset of floral induction, temperatures above 21C are neutral or nonvernalizing (8). Durkin and Hill's prior research (5) seems to indicate this when they found that 'Ace' Easter lily bulbs first receiving 5 or 6 weeks of continuous cold (10C) responded as if the subsequent warm period (21C) was simply without effect.

Langhans and Weiler (8) reported that a few weeks of 21C given after the bulb had received just a few weeks of vernalization will devernalize it. The two weeks at 21C given to our bulbs prior to vernalization may not have been enough to overcome whatever vernalization had all ready occurred. Miller and Kiplinger (9) observed that two weeks of high temperatures did not devernalize the

Easter lilies in their study. They also speculated that the bulbs received more than two weeks of vernalizing temperatures prior to their arrival.

Langhans and Weiler (8) have stated that Easter lily bulbs grown in the Pacific Northwest and harvested in early October would not be exposed to vernalizing temperatures. According to Stuart (11), the bulbs are just becoming receptive to cold temperatures and normal field temperatures on the West Coast up to this time are only slightly vernalizing if at all (8). Miller and Kiplinger (9), however, concluded that it was possible for 'Ace' lily bulbs grown in this region to receive temperatures under 21C before harvesting. Langhans and Weiler (7) found that it took approximately 7 to 10 days after bulbs were placed in cold storage before they reached the desired temperature (2-4C). They contend that this proves that vernalization would be slight during shipping. If our Enchantment bulbs did receive vernalizing temperatures in the field, as well as during storage prior to shipping and while being shipped to the Midwest, it is likely that the accumulated time period could have been longer than two weeks. If this was the case, our warm temperature treatment prior to vernalization did not have a devernalizing effect either because it was less than the weeks of vernalization all ready acquired or the bulbs had reached floral induction previously.

It is highly likely the bulbs were kept cold as much as possible before they arrived in East Lansing because there was no shoot elongation when they were initially inspected.

Evidence of the failure of the devernalization treatment to delay flowering can be seen when comparing days to flowering of our bulbs planted directly after vernalization (70 days) and those of Allen (1) which bloomed in 95 days.

Vernalization and Low Temperature Storage

Brierly (3) studied the effects of long-term cold storage at 0C on Easter lilies. Ten weeks at 0C produced plants that flowered almost 40 days later, had fewer floral buds and were several inches taller than plants from bulbs stored at 10C for 5 weeks. However, Stuart (12) stored Florida-grown Easter lilies at -0.5C for 18 weeks and observed that the bulbs remained in excellent condition with no reduction in bud count. Our control plants showed the singular effects of near freezing temperatures (-2C) on Enchantment bulbs. After one month of cold storage plants flowered a week earlier, but began to show undesirable changes in stem habit. There were no significant effects on bud number.

Our lily bulbs were vernalized and stored in their polyethylene-lined shipping crates within moist peat moss. The amount of moisture in the bulb cases during storage has an effect on the number of flowers per plant, forcing time and general plant quality (7). DeHertogh (4) states that bulbs that are overly moist or too dry may suffer from a lack of oxygen or become dehydrated.

Samples of peat moss taken and analyzed upon the bulbs' arrival and prior to vernalization showed an average moisture content of 58%. Stuart (13) states that the packing material should contain a slightly lower percentage of moisture than do the bulbs, themselves. The best results were obtained with 30 to 50% moisture content. The following year Stuart et al. (14) found that maximum storage life was achieved by packing bulbs in dry peat (20 to 30% moisture content) in polyethylene-lined cases. Earlier blooming occurred when higher-moisture peat was used, but it was undesirable for long-term storage because it stimulated rooting and sprouting during storage (15).

The final average moisture content of our peat moss samples analyzed one year later showed 24% moisture content, a loss of more than half of the original value (58%). Bulb outer acales and roots were shrunken and blackened, perhaps a result of overmoist peat moss.

There were also signs of pathogenic infection by fungi and bacteria.

The crates were opened at least twice a month to remove bulbs for study and this probably caused a shift in temperature, and consequently, condensation which contributed to the decreased quality of the bulbs. This decrease in quality due to nonoptimal storage conditions, as well as those caused by over-vernalization and low temperature storage may have interacted with the treatment variables to cause undue decrease in quality.

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