THE EFFECT OF TEMPERATURE, ANTITRANSPIRANTS AND MOISTURE LOSS DURING SIMULATED MARKETING ON REGROWTH PERFORMANCE OF LATE-SEASON, PACKAGED ROSE PLANTS

by

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ABSTRACT

THE EFFECT OF TEMPERATURE, ANTITRANSPIRANTS AND MOISTURE LOSS DURING SIMULATED MARKETING ON REGROWTH PERFORMANCE OF LATE-SEASON, PACKAGED ROSE BUSHES

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Late-season, packaged, bare-root rose plants held four weeks at 23°C lost moisture during simulated marketing and produced half as many breaks, half as many flowers, half as much total growth for the season and had a reduced field survival compared to plants held at 3°C. Waxed plants began regrowth faster, had more breaks, and more total seasonal growth than unwaxed plants when field grown following both temperatures.

In a second study, plants held two or four weeks at 20° or 30°C with minimal moisture stress subsequently had less breaks and total growth than plants held at 0° or 10°C. When moisture stress was imposed at 20°C, regrowth performance was further reduced. Waxing generally did not improve plant performance after simulated marketing when moisture stress was minimized. When planted one day after waxing and grown under shade and mist, waxed roses broke bud more rapidly than unwaxed roses.

DEDICATION

To RIW and JJB

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INTRODUCTION

Millions of rose plants are field grown each year in Arizona, Texas and California. Normally the plants are budded and then field grown for two years (7). In the fall to early winter, rose plants are mechanically harvested bare-root and stored for early spring sale. Prior to storage they may be chemically treated to cause defoliation (7, 8, 9). Typically, the plants are held bare-root in refrigerated storage between -1 to +5^{o}C for three to four months on open racks where they are misted with water daily to keep the plants from drying out, and sprayed with fungicide once or twice a week to prevent mold growth (9; Lynn Burgess, personal communication).

Upon removal from storage in late winter through spring, roses may be sent directly to a retail market. When rose plants are sold retail, the canes and roots are trimmed, and the roots are wrapped with moistened peat and packaged in plastic (8, 21). Commonly, the top and crown of the plant are dipped into hot paraffin wax (9). It is not uncommon for the plants to be held on display at ambient temperatures for four to six weeks before they are sold.

Many of the dormant, packaged bare-root rose plants fail to grow satisfactorily following purchase and planting by a consumer (Vaughn Seed, personal communication). Several of these problems could be attributed to improper handling during the last few weeks of a two-year production cycle. There may be cane dieback due to desiccation, girdling of the stem where the package is secured, sprouting or breaking of dormancy while still in the package, or death to part of all of the root system due to insufficient moisture in the packing material. Additionally, new growth may be sparse and spindly, etiolated or stunted. These problems may not be observed until the roses are planted in the garden and are compounded in roses that are held in storage until late in the shipping season (late-May through June) (Vaughn Seed, personal communication; personal observation).

In Michigan, packaged roses are commonly sold through mid-June or later (personal observation). These roses may or may not be less vigorous due to the extended storage time depending on storage conditions (9, 25). The effect of the environment on these late-season roses has not been documented, although Janne (10) and Janne and Chadwick (11) found late-season roses slightly less vigorous and Toy (24) saw a decrease in the benefits of waxing the canes for late-season roses.

In 1962, Madry attempted to relate moisture loss in to regrowth quality in roses, but a search of the literature has revealed no studies correlating effects of elevated post-storage temperatures on the subsequent regrowth and quality of rose plants. Further, very little work has been done to determine the effect of these factors on roses sold late-May through June or later. The purpose of this thesis was to determine the relative importance of temperature, moisture loss and moisture retarding materials on dormant, bare-root, packaged rose plants during the retail marketing phase.

LITERATURE REVIEW

Storage Temperature.

Roses are considered to have a short dormancy requirement. Semeniuk (22) found 10 weeks cold treatment would fulfill the dormancy requirement in *Rosa multiflora* and *R. setigera* but was not enough to induce flowering. However, Asaoka and Heins (1) reported no apparent dormancy requirement in 'Red Garnette'roses budded on *R. multiflora* when the plants were obtained from California in late October and forced 10 days later.

Yerkes and Gardner (32) stored bare-root roses in two separate experiments for 82 or 93 days at temperatures ranging from -1 to 4^{o}C and found that shoot elongation increased with increasing temperature. Plants at -1^{o}C had no shoot elongation in storage yet initiated regrowth sooner after planting than did the roses at higher temperatures. At the end of the first growing season the authors stated there were no apparent differences between storage treatments, although no quantitative data were given to substantiate this conclusion (32).

Janne (10) and Janne and Chadwick (11) also found increased shoot elongation with increasing storage temperatures from -1^{o}C to 8^{o}C after 5 1/2 and 6 1/2 months on roses that were packed in large crates lined with wax paper to retard moisture loss. In addition, the canes of the plants held at 5.5 - 8^{o}C appeared shriveled after 6 1/2 months in storage. The differences seen in growth between temperature treatments were not visibly evident after two months in the field (10, 11). In a separate experiment on quick freezing of dormant rose plants, Janne (1950) found that holding roses at -3.9°C as described above for about four months killed all the roses at that temperature while holding at -2° to -1°C led to 100% suvival of the roses (10).

Boersig and Negm (2) report that winter storage temperatures of 5 - 15°C increase the metabolic activity of some dormant woody plants, ultimately resulting in carbohydrate depletion (2). Higher temperatures cause rose plants to break dormancy (10, 11, 15, 32). Thus, at elevated temperatures, stored carbohydrates are lost directly by metabolism and indirectly when the etiolated new growth is removed for retail display or dies after planting (2, 19, 15).

The recommended storage temperature for dormant roses is -1 to +2°C (8, 9, 11, 32). In storage, temperatures are kept as low as possible to favor dormancy without causing permanent cold damage. After storage, packaged roses are often placed on display in or in front of a retail nursery, and are generally subjected to ambient temperatures and relative humidities. Temperatures during marketing may exceed 30°C (Personal observation). It has already been established that the rate of growth in stored roses increases with increasing temperatures (10, 11, 32), and that the increased metabolic activity can deplete stored food reserves (see Boersig and Negm, 1987). Furthermore, an increase in temperature almost certainly causes an increase in the rate of transpiration when all other factors remain constant (4). An increase in transpiration rate may subsequently cause desiccation. We know of no research that is specific to the temperatures encountered during the post-storage phase of rose production.

Desiccation stress.

While it is widely believed that desiccation stress is a problem in storage of plant materials the relationship has not been well documented. Desiccation during storage has been reported to cause delayed bud break and poor subsequent performance in woody ornamentals (13, 16). Fuchigami (unpublished) concluded that desiccation is the primary cause for losses of bare-root, deciduous transplants (5) but he gave little direct documentation.

Roses present a special problem because they break dormancy quickly if there is sufficient moisture (32). Yerkes and Gardner (1934) found roses would begin regrowth during a 93 day storage period at 2°C with as little as 42% relative humidty. The amount of regrowth was greater when the relative humidity was 58%. No sprouting was observed on plants at 0°C regardless of relative humidity (32).

Rose canes are sensitive to desiccation. Cane dieback is a common symptom of desiccation in bare-root rose plants and visual symptoms are browning, shriveling, and/or death of the cane tips (14; personal observation). Cane dieback may be observed during storage (9) or after removal from storage.

In 1956, Mahlstede (16) compared storage humidity to weight loss and percent suvival over 20, 40, 60 and 80 days in storage at 4°C for rose cultivars 'Lowell Thomas' and 'Chysler Imperial'. Plants at 100% relative humidity had 100% survival regardless of storage duration, while roses at 76% relative humidity had 40% survival after 20 days storage. None of the roses survived the longer storage durations at 76% relative humidity. At 85% relative humidity 'Chrysler Imperial' had 100% survival after 20 days storage and 20% survival for 40 days storage, while 'Lowell Thomas' had 60% survival after 20 days storage. None of the 'Chrysler Imperial' survived 60 or 80 days of storage, and none of the 'Lowell Thomas' survived past the 20 day storage at 85% relative humidity (16).

Mahlstede exposed roses to 50, 75 or 100% relative humidities at 7°C for an unspecified duration. Measurements were taken on shoot number and length, mold growth, percentage cane dieback, root growth and cane percent moisture. Although there were no significant differences in the shoot number and length and percentage cane length dead to relative humidity there was a trend towards a decreased response as the humidity was lowered. In addition, there was more mold growth, more root growth and more cane moisture at the higher relative humidities (see 16).

Mahlstede and Fletcher (16) found that rose plants stored with their roots in contact with liquid water actually absorb water. At 100% relative humidity without root contact with water, roses lost "extra" water (not defined) until equilibruim with the environment was reached (16).

Madry (14) studied dormant roses that were condemned by the Ohio Department of Agriculture inspectors of nursery stock. The pupose of his study was to determine the plant quality of the condemned roses. Initial percent moisture content of the canes and percent survival at the end of the growing season were measured. Madry found that 94.3% of the condemned roses were unfit for sale according to his evaluation. He concluded that any dormant rose plant which had less than 50% cane moisture or excessive etiolated shoots should not be sold although no data was presented in the paper to substantiate these conclusions (14).

In experiments with woody tree and shrub transplants, Fuchigami compared the storage of three species on open racks to those wrapped in 4-mil polyethylene at 1^{o}C for three months. The polyethylene wrapped plants performed much better after planting than the unwrapped plants when evaluated on percent bud break and length of new growth. The effect was especially apparent in Hawthorn where all of the plants wrapped in polyethylene grew after planting while none of the unwrapped plants broke buds. It was concluded that water status is important to regrowth potential for woody plants (5).

In his thesis, Maqbool (18) packaged various herbacious perennials in five different materials to observe the effect of water loss. The perennials were packaged in 4-mil polyethylene, 4-mil polyethylene with perforation, cellophane, cardboard or burlap for 6 months. He found a highly significant inverse linear relationship between the regrowth quality of the plants and the amount of water loss during storage (18).

Molds.

Mold growth during storage has been documented for roses and other plant materials (9, 16, 18, 23, 24, 25, 26, 28; Lynn Burgess, personal communication). It is recommended practice to defoliate and trim unhardened wood of roses before storage to decrease contamination and infection sites (9, 15). During storage rose plants may be routinely sprayed with fungicides to prevent mold growth (9; Lynn Burgess, personal communication). The dieback on cane tips that occurs during storage may support mold (35; personal observation). Yerkes and Gardner (32) suggested that the amount of decay on roses depended more on maturity and cultivar than environmental humidity (32). Normally, once the plants are removed from storage molds do not survive, presumably due to the drier environment (15).

Molds such as Penicillium, Botrytis and Rhizopus are saprophytic and occur in high humidity, cold storage rooms (15). These molds may grow on the storage walls, paper wrappings or cotton string used to bundle some nursery stock (12). At a storage temperature of $0^{o}C$ most decay organisms are slow to devitalize the plants, but can quickly make them appear undesirable (32, 12). Grey mold (Botrytis cinerea) is reported to be the most common fungi associated with rose canes during storage (28). Various systemic fungicides, sodium salts and sulphur dusts have been used to control Botrytis during rose storage (12, 16, 23, 28). For less severe mold problems, increasing air circulation around the plants has been recommended to decrease mold growth (15, 16).

In 1959, Toy and Malhstede exposed roses to 55, 75 or 100% relative humidities at $7^{o}C$ (storage duration not known). They found a general increase in mold development with increased humidity with 50% more mold at 100% relative humidity than at 50% relative humidity. Waxing the canes decreased mold growth 30% (25).

Ethylene.

Relatively low concentrations of ethylene gas are reported to cause a reduction in vigor or death to ornamental plants (9, 28), and cause abortion of growing tips (29). At higher temperatures, rose plants are more sensitive to ethylene (20).

In 1959, Uota (28) exposed rose plants to fresh air, 2 ppm ethylene or 10 ppm ethylene for five months at 0°C. Plants exposed to ethylene grew slower, had more cane dieback, and flowered later than the controls. In general, plants exposed to ethylene tended to break new growth from the basal buds and have a higher respiration. Initial growth was short and bushy (28).

More recently, Meadows and Richardson (20) exposed dormant roses of the cultivar 'Viva' to 0, 1, 10, 100, or 1000 ppm ethylene at 0 or 5°C for four weeks. The plants were then potted and regrown in the greenhouse. The 5°C plus 1000 ppm ethylene treatment caused an increase in cane dieback and a decrease in bud break. While 0°C storage temperature decreased the damage of ethylene exposure, it did not eliminate it (20).

Controlled Atmospheres.

Many plant commodities are commonly stored in low oxygen and elevated carbon dioxide. Controlled atmosphere storage reduces respiration and correlates with an extended storage life of many horticultural crops (3). Controlled atmosphere may also decrease ethylene production and reduce pathogenic and saprophytic decay (3).

Uota (28) exposed stored roses at 0°C to normal air, an atmosphere of 10% CO_2 and 5% O_2 or 20% CO_2 and 5% O_2 for 150 days. He found the plants previously in 10% CO_2 and 5% O_2 subsequently grew better and bloomed earlier than the controls or plants that were stored in 20% CO_2 and 5% O_2.

Plants held in 20% CO_2 had less growth than the controls but bloomed at the same time. Supplementing CO_2 caused no visible injury to the rose canes (28).

New growth on dormant rose stock during shipping and holding is not desirable. Toy and Mahlstede (1960) experimented with elevated levels of CO_2 to retard growth on roses and herbacious perennials during storage. They found that a CO_2 concentration of 40% or greater for two weeks at an average 27^{o}C inhibited shoot and root growth in packaged rose plants but caused no visible signs of injury. The increased CO_2 subsequently retarded bud break in the field in roses and hastened bud break in the field in perennials (26).

Furuta and Perry (6) used stems of _Rosa_ and _Hibiscus spp_. stored at 24 to 28^{o}C for 1 to 4 weeks in normal air, 5% CO_2 or 10% CO_2 to study the change in free amino acids during storage. They related an increase in CO_2 to an increase in free amino acids and a decrease in bud gorwth during storage. The increase in CO_2 also delayed the onset of growth after storage. Amino acid content of stored plants was found unsatisfactory for determination of viability (6).

Storage duration.

As storage time is lengthened plant materials generally begin root growth, bud swell and bud break (see Mahlstede and Fletcher, 1960). Lower storage temperatures may extend storage life but cannot necessarily eliminate growth. Little research has been reported on the effect of long storage periods on roses.

Janne (10) and Janne and Chadwick (11) stored roses at a variety of temperatures for 5 1/2 and 6 1/2 months. Plants held in storage for 6 1/2 months had longer new shoots develop during storage and cane shriveling at the higher storage temperatures. In the later planting, roses grew slower and treatment differences were less pronounced than in the earlier planting. It was concluded that roses could be held successfully in refrigerated storage as late as June 30 and still produce high quality plants. The best success in late season planting was found when storage temperatures were gradually increased before planting (10, 11).

In 1959, Toy and Mahlstede planted 'Crimson Glory' roses on April 29, May 27 and June 24. A significant difference was found in plant performance for flower number, percent original cane survival, total new growth, root weight, number of new roots, number of plants surviving the winter, and flower number the second season. In every case there was a decreased response with increasing storage length (25).

Practices to improve performance of rose plants.

Before being sold retail, dormant rose plants are packaged. The packaging system that has been developed involves "wrapping" the roots with a moistened peat medium using a root wrapping machine (21; Lynn Burgess, personal communication). This machine rolls the media and plant into a piece of waterproof inner wrapping paper. The entire root-media roll then slips neatly into a polyethylene bag that is tied tightly at the crown of the plant (personal observation).

To protect the packaged plants from water loss, nursery practice is to wax the canes and crown before shipping. Tukey and Brase (27) are commonly cited as the first to demonstrate the effectiveness of wax. However, a close examination of their results does not support their conclusion that wax increased rose plant performance. The extensive experiment had 12 treatments including combinations of cording (laying plant material horizontal with roots exposed and coverd with moist excelsior), pruning branches 1/3 to 1/2, melted or miscible paraffin or crude wax applied to the canes or roots, trenching roots in sand, and stacking plants in bins. Of the twelve storage treatments, eight had to do with coating the rose canes with some type of paraffin or wax (see Table 1). The temperature during storage ranged from 0.5^{o} to $7^{o}C$, and the relative humidity ranged from 93 to 95%. Storage duration was not specified. The cultivar 'Ophelia' showed either no benefits or detrimental effects from waxing compared to the controls (Table 1). 'Luxemburg' possibly had less plant death with wax, although when corded in bins and pruned there was no difference from the waxed treatments. In 'Los Angeles', waxing might have been beneficial in cording and coating

Table 1. Selected data from Tukey and Brase, 1934.

	AVERAGE RATING*			NUMBER OF WEAK OR DEAD PLANTS		
	Ophelia	Los Angeles	Luxemburg	Ophelia	Los Angeles	Luxemburg
UNWAXED TREATMENTS	**					
I. Corded in bins	5.8	3.9	3.3	0	4	3
II. Tops pruned corded in bins	4.7	3.6	4.9	1	4	1
X. Roots unprotected corded in bins	5.3	3.0	3.2	0	5	4
WAXED TREATMENTS						
III. Paraffin wax on tops corded in bins	5.3	5.2	4.9	0	0	1
V. Yellow crude scale wax on tops corded in bins	5.7	4.8	-	0	1	-
VI. Paraffin wax on tops tops pruned, corded in bins	4.8	4.3	4.2	1	2	2
VII. Cold miscible paraffin on tops (Micol 180), corded in bins	5.1	2.8	4.9	0	7	0
VIII. Cold miscible paraffin on tops (Micol 2015), corded in bins	4.6	2.9	4.6	1	6	1
IX. Paraffin wax on tops and roots corded in bins	4.7	5.0	-	1	0	-

*plants rated on a from from 0-7 as follows:
7=very vigorous, 6=vigorous, 5=medium vigorous, 2=weak, 1=very weak, 0=dead
Rating represents an average of 10 replicates.

**No statistics presented in original paper with melted paraffin and cording and coating with yellow crude scale wax. The differences were small and statistics were not presented in the original paper. Pruning and coating with cold miscible paraffin appeared to have deliterious effects on 'Los Angeles' (27).

St. Joseph Toy was the first to convincingly document the benefits of waxing rose plants (24). He found the waxing treatment decreased moisture loss of the canes, decreased transpiration by as much as 25%, and increased shoot and root growth after planting. In addition, wax decreased mold growth, created a barrier to gas exchange and decreased respiration by 20%. Waxed plants improved performance over the non-waxed rose plants even during the second year's growing season. Late season planting (June) reduced the positive effects of the wax. Toy observed that the wax does not penetrate the tissue and, therefore, does not harm tissue while hot water at the same temperature does (24). Workman confirming Toy (30), documented consistent increased flower production in the field for 2 years after the initial treatment with wax (31). All experiments with wax were conducted at low storage temperatures (24, 30, 31).

Despite the favorable results, rose growers still question the usefulness of waxing. Concern remains over the possibilities of increased cane temperature and restriction of oxygen due to waxing (28). It has been proposed that the wax may create a modified atmosphere around the cane. Many growers feel the wax is unsightly and detracts from the visiual quality of the plants in the eyes of the consumer (Vaughn Seed Company, personal communication).

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CHAPTER I

INFLUENCE OF TEMPERATURE AND ANTITRANSPIRANTS DURING SIMULATED MARKETING OF PACKAGED ROSE BUSHES ON FIELD PERFORMANCE

ABSTRACT

Late-season, packaged, bare-root roses (Rosa) of the cultivars 'Show biz', 'Tropicana', 'Hotel Hershey' and 'Femme' were held under simulated retail marketing conditions at 3°C or 23°C for four weeks. Moisture content of canes decreased only slightly while plants were held at 3°C but decreased markedly at 23°C. Wax partially reduced the rate of moisture loss at 23°C though the antitranspirant (Cloud Cover) had little, if any, effect. Plants held at 23°C produced half as many breaks, half as many flowers, and half as much seasonal cane growth; had reduced field survival; and initiated breaks while packaged that survived poorly in the field. Waxed plants began regrowth faster, had more breaks, greater season cane growth and, enhanced flower production in 'Showbiz'. Antitranspirant-treated roses generally performed no better than did nontreated roses.

INTRODUCTION

Rose plants are commonly field grown, fall harvested and stored bare-root to ensure early spring shipping. The optimum temperature during storage is from -1^{o} to $+2^{o}C$ (8, 9, 18). In preparation for marketing through retail stores in the late winter through spring, the bare-root plants are removed from storage, trimmed, and the root systems are covered with moistened peat moss and wrapped in plastic tied near the crown.

Waxing has been reported to retard water loss from the canes and improve subsequent field performance as measured by cane and flower production (3, 14), with a reduced effect for late-season roses (13). Unfortunately, waxed canes are considered unsightly and may detract from the visual quality of the packaged roses (Vaughn Seed, personal communication). There are several antitranspirants currently on the market other than wax which would not visually detract from the plant. There is interest by nurserymen to determine if these antitranspirants could be used in place of wax on dormant packaged rose plants since they would not appreciably alter the appearance of the canes. There is no information available as to whether antitranspirants could replace the wax on rose canes.

Snyder (10) used five different polyvinal antitranspirants on 30 species of woody ornamental plants. Plant response varied from an increased water loss effect, to no effect, to a decrease in water loss. Spraying or dipping were found to be equally effective, but effectiveness decreased with time. He concluded that the effectiveness of polyvinyl materials in reducing water loss depends on the chemical and plant materials and the length of time following treatment (10).

Many metabolic antitranspirants have been found to be toxic to woody and herbacious plant materials (5). Others may cause suffocation due to persistence of the chemical (5). Success is generally found when treatment with an antitranspirant reduces transpiration by creating a physical barrier or exhibiting a systemic influence on closing the stomates (5, 6, 7, 12, 15, 17).

Albregts and Howard (1) investigated several antitranspirant materials in combination with irrigation for reducing water loss on the foliage of newly transplanted, bare-root strawberry plants. Plants were placed in the field and were evaluated after 14 days. The use of antitranspirants with or without intermittent overhead irrigation in the field did not increase yield over the controls (1).

Antitranspirants have also been used in potted and container-grown plant to retain soil moisture (4, 16) and in turf to retard growth by decreasing transpiration (6). Stahnke and Beard investigated the use of antitranspirants on turf (11). Two of the treatments reduced the transpiration rate of creeping bentgrass 26-59% for 48 house without visual damage or increase in leaf temperature (11).

In comparison, ABA was effective in reducing transpiration in bermudagrass about 25% but also decreased the growth rate. The remaining treatments were detrimental to the turf (11).

Some woody plants decline in vigor as storage length is increased (2, 14). On a storage study on red raspberry canes, Barritt and Torre found the later they held plants in storage, the lower the survival rate after planting (2). Toy and Mahlstede saw a significant decrease in every aspect of rose plant performance measured as storage length increased (14). Late-season roses may be in storage as long as six months. Packaged roses seldom are refrigerated during marketing and may be exposed to elevated temperatures for several weeks before they are sold and planted. A search of the literature has revealed no reports on the effects of elevated temperatures on moisture loss from canes or on subsequent field performance of late-season, packaged rose bushes.

The following experiments were conducted to determine if the antitranspirant Cloud Cover (a polyvinyl resin-based antitranspirant) could provide adequate protection to late-season packaged rose plants when compared with waxing or no treatment. For purposes of comparison, packaged roses were held for four weeks of simulated marketing at 3°C or 23°C and monitored for moisture content and subsequent field performance.

MATERIALS AND METHODS

Poststorage treatments. Rose plants of the cultivars 'Femme', 'Tropicana', 'Hotel Hershey' and 'Show Biz' of previous unknown origin were removed from commercial refrigerated storage (1-3°C) on May 4, 1985. Plants were disbudded as necessary, top-pruned to 16 inches and root-pruned to 12 inches. The canes and crown were dipped into hot wax (80°C) or an antitranspirant (Cloud Cover) diluted 1:10 or left untreated. After treatment, the roots were wrapped in moistened peat moss and secured in a polyethylene wrap according to common nursery practice.

Packaged roses were held four weeks under controlled temperature and simulated marketing conditions of either 3°C or 23°C. The relative humidity ranged from 40 to 50% at 3°C and from 20 to 30% at 23°C.

Each week of the simulated marketing period beginning at time 0, 3 canes were collected for moisture analysis from each treatment. Moisture content was determined by comparison of weights before and after drying at 70°C for 5 days. Wax was calculated to be about 3% of the dry weight of the canes (Appendix A).

All roses were planted and watered in at the Horticultural Research Center, East Lansing, Michigan, on June 1, 1985 in a heavy loam soil. Six plants were planted for each treatment/cultivar. The few days following planting were particularly windy, dry and harsh. Plants were irrigated, lightly cultivated as needed to control weeds, and sprayed with fungicides as needed for control of blackspot throughout the growing season.

The number of bud breaks were counted weekly for the first 6 weeks following planting. The field survival of buds initiated during simulated marketing was also monitored.

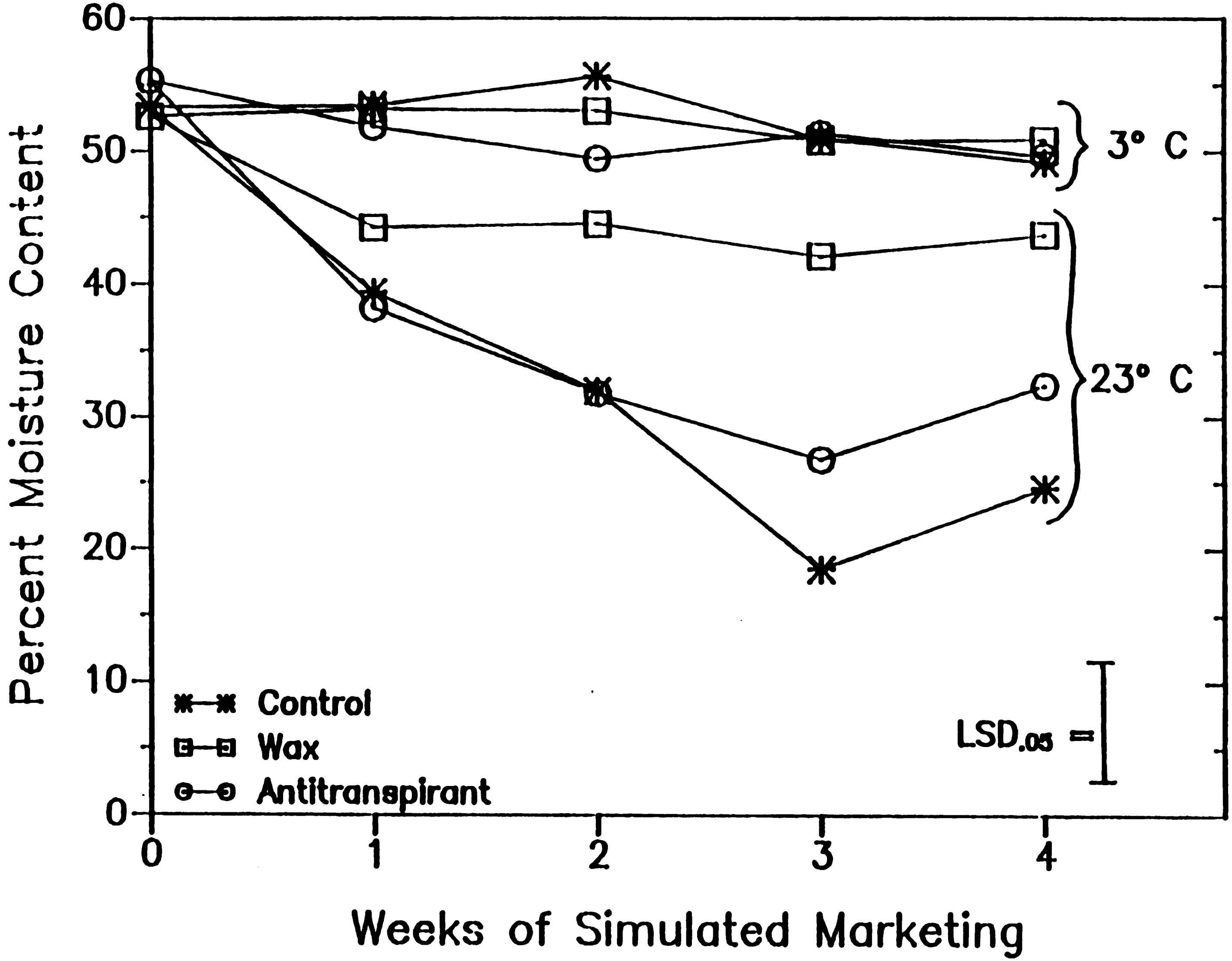
Flower production initiated in some treatments the fourth week after planting and was monitored 2 to 3 times weekly until flowering ceased. Flowering stems were cut back to the first strong five leaflet node when the flower sepals had completely reflexed and the petals were opening. The first killing frost recorded the second week of November was unusually late for this growing region. After onset of dormancy, the number of lateral canes and length per cane were recorded for each plant. Percent survival of plants for each treatment group during the first season was measured on November 7, 1985. Plants were mounded heavily with straw in December and were rated the following spring after bud break (June 11, 1986) for winter survival on the basis of the presence or absence of new lateral breaks.

The data were analyzed as a completely randomized 4-way analysis of variance with 6 plants per treatment.

RESULTS

Moisture content of canes during simulated marketing. There was a marked decline in cane moisture content during the 4 weeks of simulated marketing at 23°C (Figure 1.1).

Figure 1.1. Percent moisture content of packaged rose canes during simulated marketing at 3° and 23°C. At time 0, canes were dipped into wax, antitranspirant or were left untreated.


60
50
40
30
20
10
0
Percent Moisture Content
0
1
2
3
4
Weeks of Simulated Marketing
3° C
23° C
Control
Wax
Antitranspirant
LSD.05 =

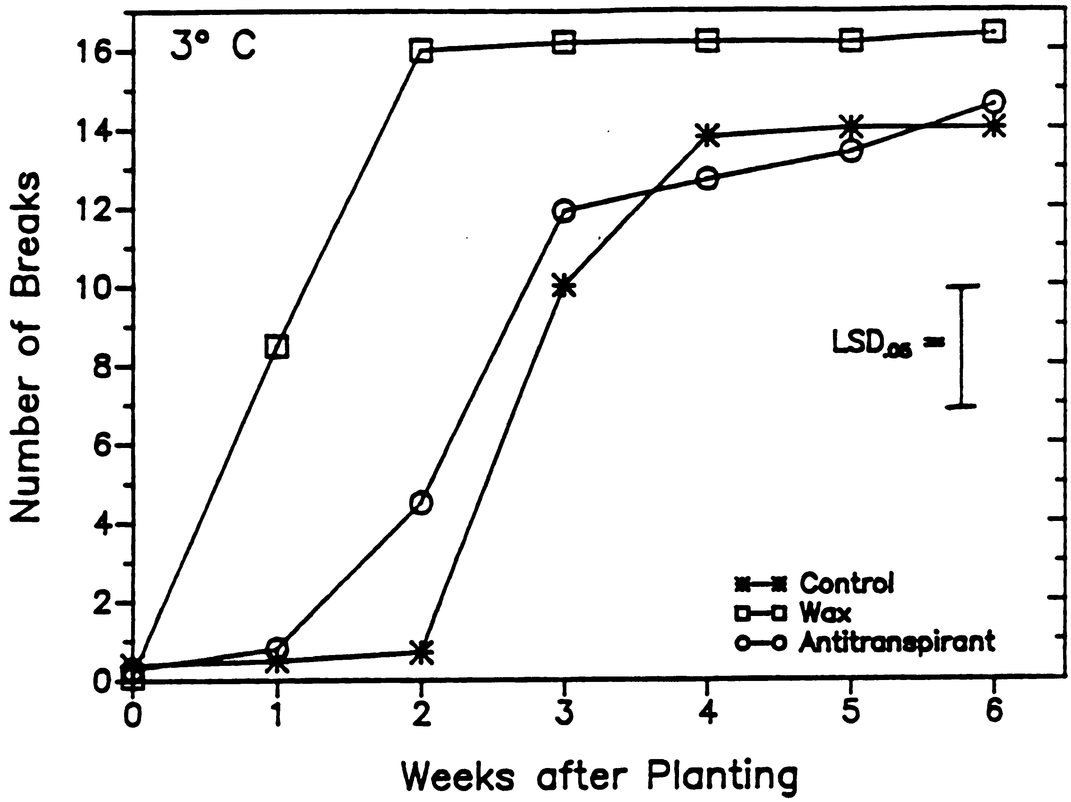
Waxing reduced but did not completely prevent the drop in moisture content. Over the 4-week period, waxed canes at 23°C averaged 44% moisture content compared to an initial value of 54%. The antitranspirant provided only slight if any protection against moisture loss at 23°C (Figure 1.1). Canes treated with the antitranspirant averaged 33% moisture while untreated canes averaged 28% moisture ($LSD_{.05}$ = 4.0).

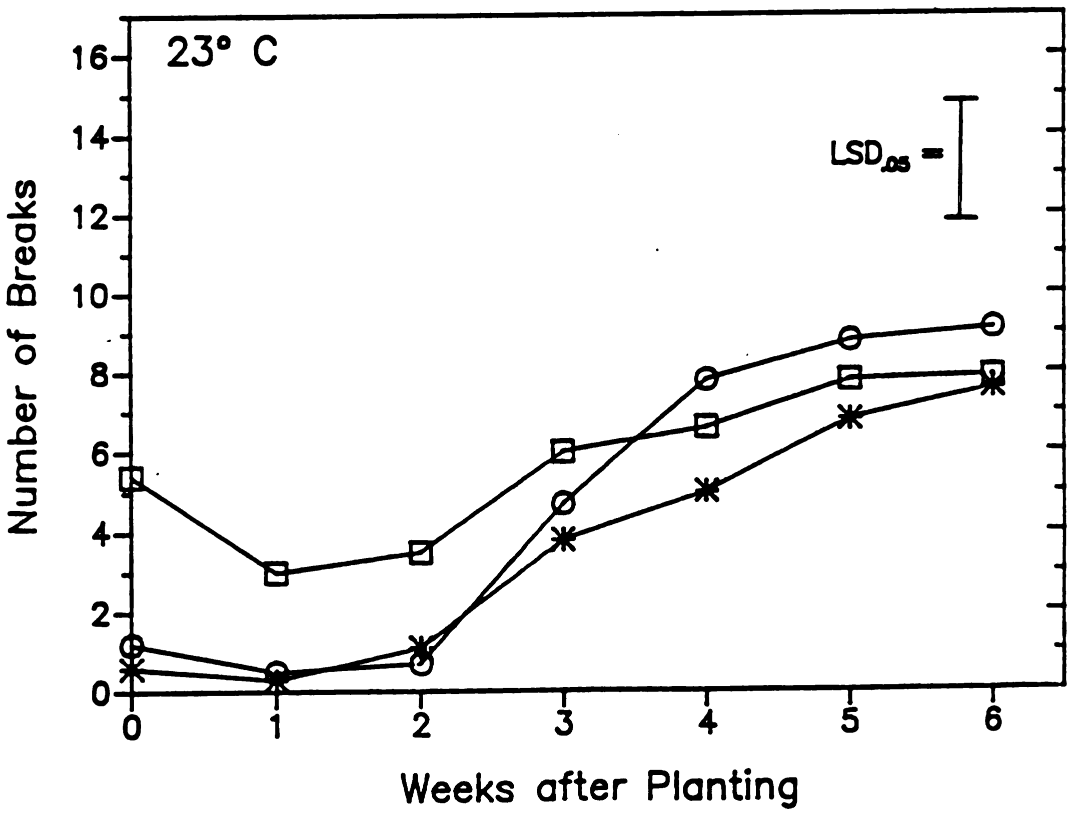
At 3°C, there were no significant differences in moisture content between plants dipped in wax, the antitranspirant or not treated (Figure 1.1). Statistically, all 4 rose cultivars responded similarly with respect to moisture content (data not shown).

Breaks initiated during simulated marketing and post-planting. Roses which had been waxed and held at 23°C had an average of 5 bud breaks per plant for each of the 4 cultivars (Figure 1.2). Only about one-half of these shoots survived the first week in the field (data not shown) which accounts for the drop in breaks shown between weeks 0 and 1 for waxed roses previously held at 23°C simulated marketing (Figure 1.2b). Of the few breaks noted on plants in other treatment combinations, very few survived the first week in the field (data not shown).

Waxed roses of all 4 cultivars initiated rapid bud break in the field following simulated marketing at 3°C (Figure 1.2a). After the second week, there was no further initiation of new breaks. In contrast, antitranspirant-

Figure 1.2. Number of viable breaks on rose plants for the first six weeks following planting as influenced by four weeks simulated marketing at 3^{o} or 23^{o}C and by moisture barrier treatment to canes.


3° C
Number of Breaks
LSD.05 =
Control
Wax
Antitranspirant
Weeks after Planting


23° C
Number of Breaks
LSD.05 =
Weeks after Planting

treated and untreated roses held at 3°C did not initiate significant bud break until the second and third weeks in the field respectively (Figure 1.2a). By the fourth week, though, the differences between moisture barrier treatments were less marked.

Four weeks simulated marketing at 23°C retarded the rate of bud break and markedly reduced the total number of breaks after 6 weeks compared to roses held at 3°C (Figure 1.2). Neither of the 2 moisture barriers improved performance in the field markedly over the controls. It should be noted that waxed plants at 23°C did initiate earlier breaks but these occurred in storage as discussed previously and survived poorly in the field.

Flower production. The temperature of the simulated marketing period greatly affected total rose production by the 4 cultivars (Table 1.1). With few exceptions, total rose production following 3°C simulated marketing was 2 to 3 times that following 23°C simulated marketing for all combinations of cultivar and moisture barrier treatment. Overall, roses held initially at 3°C produced 29 flowers per plant compared to 15 flowers per plant following 23°C treatment.

'Show Biz, a floribunda rose, produced the most flowers of the 4 cultivars tested. Flower production was greatest for this cultivar following waxing and storage at 3°C (Table 1.1). This increase was due primarily to a second burst in flower production by waxed plants between weeks 13 and 17

Table 1.1. Total number of flowers produced during the first growing season by 4 cultivars of roses as influenced by moisture barrier and temperature during 4 weeks simulated marketing of packaged plants prior to planting.

	Cultivar							
	'Show Biz'		'Tropicana'		'Hotel Hershey'		'Femme'	
	Temperature (C)							
Moisture Barrier	3	23	3	23	3	23	3	23
Wax	82	35	21	11	34	16	17	6
Antitranspirant	38	27	19	10	31	10	17	8
None	34	18	14	10	28	20	14	5
$\bar{x}$	51	27	18	10	31	15	16	6

$LSD_{.05}$ = 6 for all comparisons.

which was largely absent in other treatment combinations (Figure 1.3).

Waxing consistently increased total rose production compared to nontreated controls in the cultivars `Tropicana', `Femme' and `Hotel Hershey' when held at 3°C (Figure 1.3; Table 1.1). However, this increase was quite small on a relative basis, accounting for an increase of only 5 flowers per plant the entire season averaged for these 3 cultivars. Plants treated with the antitranspirant and held at 3°C were generally intermediate in terms of rose production (Figure 1.3; Table 1.1).

Neither of the 2 moisture barriers consistently improved flower production by `Tropicana', `Hotel Hershey' or `Femme' after 4 weeks holding at 23°C (Figure 1.3; Table 1.1). However, both waxing and antitranspirant treatment significantly increased the number of flowers produced by `Show Biz' plants previously held at 23°C (Figure 1.3).

First season cane production. The total number of surviving shoots and total cane production were both significantly affected by temperature, moisture barrier and cultivar (Table 1.2). Cane length was significantly different only between cultivars. Interactions were not statistically significant, therefore, only main effects are discussed.

By the end of the season, rose bushes held 4 weeks at 23°C prior to planting had produced about one-half the total amount of cane growth compared to plants initially held at 3°C (Table 1.2). This effect was related to the number of

Figure 1.3. Cumlative flower production for 'Show Biz', 'Tropicana', 'Hotel Hershey' and 'Femme' following four weeks similated marketing at 3^{o} or $23^{o}C$. Prior to simulated marketing, canes were dipped into wax, antitranspirant, or left untreated.

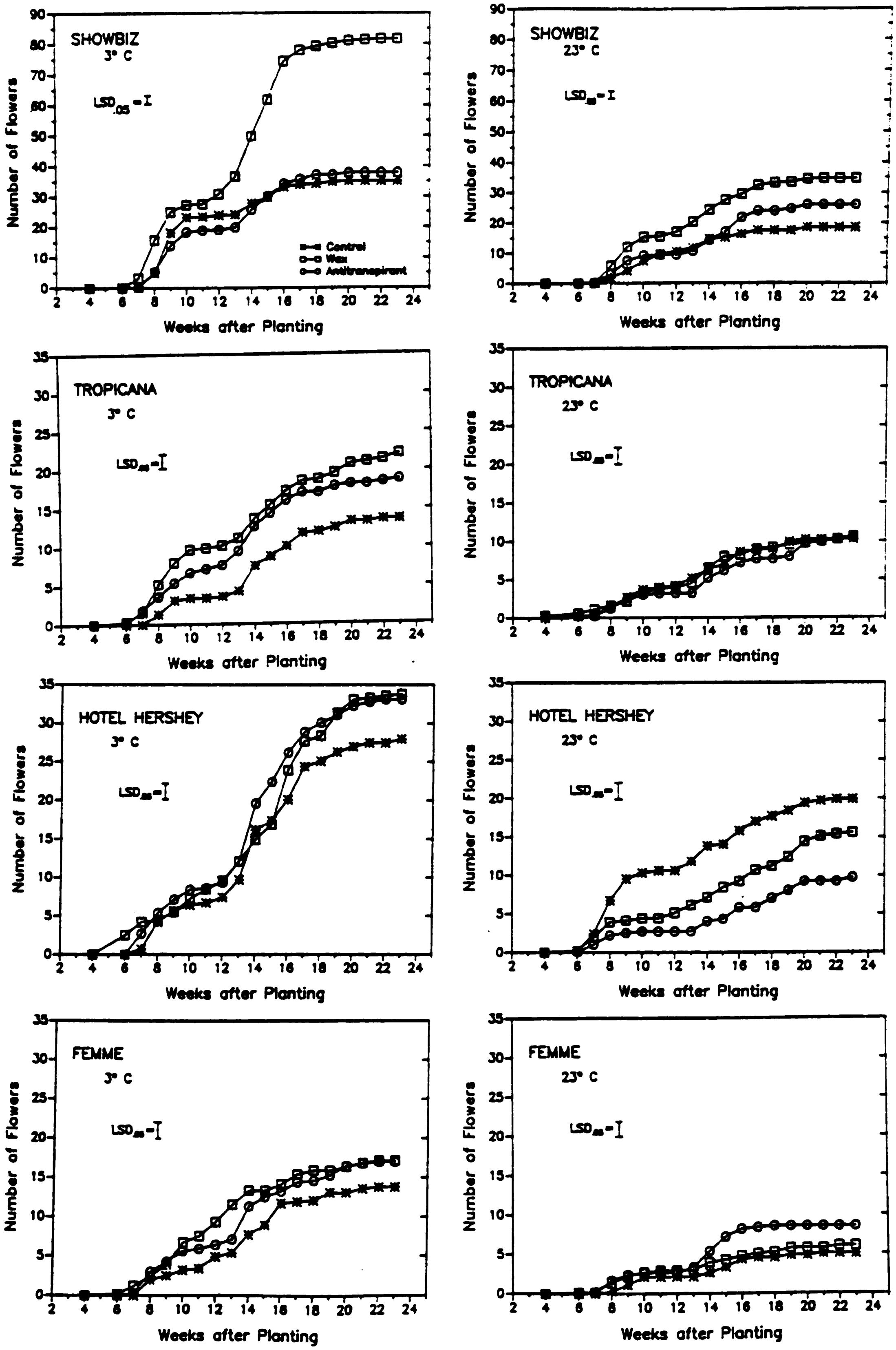

SHOWBIZ
3° C
$LSD_{.05}$ = I
Control
Wax
Antitranspirant
SHOWBIZ
23° C
TROPICANA
3° C
TROPICANA
23° C
HOTEL HERSHEY
3° C
HOTEL HERSHEY
23° C
FEMME
3° C
FEMME
23° C
Number of Flowers
Weeks after Planting

Table 1.2. Total number of canes, length per cane and total cane length measured at the end of the first growing season by 4 cultivars of roses after treatment with moisture barrier and holding 4 weeks at either 3^{o} or 23^{o}C of simulated marketing conditions prior to planting. No interactions were significant at the 5% level so only main effects are presented.

	Number of canes	Length/cane (cm)	Total cane length (cm)
<u>Holding temperature</u>			
3^{o}C	12.3	19.1	235
23^{o}C	6.4	18.6	120
	(1.4)*	(NS)	(27)
<u>Moisture barrier</u>			
Wax	10.7	19.9	213
Antitranspirant	9.3	17.5	163
None	8.1	19.1	155
	(1.7)	(NS)	(34)
<u>Cultivar</u>			
\`Show Biz'	13.8	8.8	121
\`Tropicana'	8.8	27.2	239
\`Hotel Hershey'	8.8	20.3	179
\`Femme'	6.2	19.1	118
	(4.1)	(2.0)	(39)

NS - nonsignificant at .05 level

*Numbers in parentheses are $LSD_{.05}$ for mean comparison with in a column.

breaks since there was no significant difference in length per cane (Table 1.2).

Waxing of canes prior to simulated marketing had a significant but less dramatic effect on cane length (Table 1.2). Waxed roses produced 37% more cane length while antitranspirant treatment did not significantly increase cane production compared to untreated roses. The effect of moisture barrier on total cane production was primarily due to an increased number of canes and not to length per cane (Table 1.2).

The 4 cultivars showed variations in both number of breaks and length per cane depending on their relative growth habits (Table 1.2). For example, \`Show Biz' had many short canes whereas \`Tropicana' had fewer, longer canes and overall produced the greatest cane length.

Percent survival. All rose plants held initially for 4 weeks at 3°C survived the first growing season in the field. Overall, 88% of all plants held at 23°C survived the first growing season into fall. Of the 4 cultivars, \`Femme' was the most sensitive to simulated marketing at 23°C with only 72% survival through the summer. In contrast, \`Tropicana', \`Hotel Hershey' and \`Show Biz' had 94%, 89% and 94% survival, respectively, following the 23°C treatment (data not shown).

Percent survival after the first winter as influenced by temperature and moisture barrier treatment prior to planting is shown in Table 1.3. Poorest survival was observed for untreated roses held at 23°C during simulated marketing

Table 1.3. Percent of rose bushes which initiated bud break the second season after planting. No statistical analysis was performed.

	Simulated marketing temperature	
Moisture barrier	3	23
Wax	96	75
Antitranspirant	67	63
None	75	38

the previous year. In contrast, only one plant ('Femme') died that was waxed and held at 3°C prior to planting.

DISCUSSION

The temperature at which packaged rose plants were held during 4 weeks simulated marketing had a marked influence on the subsequent field performance. Compared to plants held at 23°C, plants held at 3°C had much higher moisture content of canes at planting, produced nearly twice as many bud breaks, twice as many flowers, and twice as much total cane growth. In addition, all plants held initially at 3°C survived the first growing season in the field compared to an average of only 88% of all plants held at 23°C. The negative effects of 23°C were noted for all treatment combinations, independent of the 4 rose cultivars tested or moisture barriers used to protect canes.

Waxing of rose canes prior to simulated display decreased the drop in moisture content observed in untreated plants during simulated marketing at 23°C (Figure 1.1) and generally improved the overall performance of rose plants as has been reported in previous studies (3, 14). There was no difference in moisture content between waxed and nonwaxed canes 4 weeks at 3°C. Waxed plants initiated bud break earlier than untreated roses, although at 23°C the bud break occurred prior to planting (Figure 1.2). Waxing of canes led to a 37% increase in the total cane length produced in the first season following both 3° and 23°C primarily by increasing number of bud breaks per plant (Table 1.2). Flower production was enhanced in waxed 'Show Biz' roses (Table 1.1). In addition, rose plants with waxed canes had a much better percent survival through the first winter compared to controls.

Antitranspirant treatment prior to simulated marketing generally did not improve the performance of rose plants compared to untreated rose plants, though it was associated with a slight increase in flower production in some cases (Table 1). Antitranspirant did not prevent moisture loss while holding at 23°C during simulated marketing.

No difference could be detected in the moisture content of waxed and unwaxed canes following 4 weeks at 3°C (Figure 1.1). The beneficial effect of wax may have been related to continued protection from dehydration following planting, particularly in light of the harsh weather conditions at that time.

Though waxing prevented moisture loss during simulated marketing at 23°C, it also caused excessive bud break. These etiolated shoots performed poorly in the field and also would have rendered the plants unsalable. Yerkes and Gardner (18) noted that bud break increases with the moisture content of packing material during bare-root storage at 7-9°C. The higher moisture content of the waxed plants combined with 23°C might have been responsible for promotion of bud growth prior to planting.

The results of this study indicate that 4 weeks at 23°C has an unacceptable impact on the subsequent performance of packaged rose plants. It should be noted that these experiments were initiated relatively late in the season (May 4). It is possible that the temperature effect may not be as severe earlier in the spring when the carbohydrate storage reserves of the plants should be higher. Waxing only partially overcame the poor performance at higher temperatures and actually induced an excessive number of breaks during holding. The antitranspirant Cloud Cover was generally ineffective. The best practical solution is to continue waxing canes and to hold packaged roses under cool conditions during retail display.

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CHAPTER II

EFFECT OF TEMPERATURE AND MOISTURE STRESS ON REGROWTH PERFORMANCE OF LATE-SEASON, BARE-ROOT, PACKAGED ROSE PLANTS

ABSTRACT

Late-season, packaged, bare-root roses (Rosa) of the cultivars 'Femme' and 'Hotel Hershey' held for simulated marketing 2 or 4 weeks with minimal moisture stress at 20° or 30°C subsequently had fewer breaks and less total regrowth than plants held at 0° or 10°C. With moisture stress imposed at 20°C, regrowth performance was further reduced. At 10° or 20°C, rapid etiolated bud breaks occured during holding. Waxing generally did not improve plant performance after simulated marketing when moisture stress was minimized, but prevented moisture loss when moisture stress was induced. When planted one day after waxing and grown under shade and mist, roses broke bud more rapidly than unwaxed roses.

INTRODUCTION

Rose plants are commonly field grown, fall harvested and stored bare-root to ensure early spring shipping. The optimum storage temperature is from -1^{o} to $+2^{o}C$ (2, 4, 6). In preparation for marketing through retail stores in the late winter through spring, the bare-root plants are removed from storage, trimmed, and the root systems are covered by moistened peat moss and wrapped in plastic tied near the crown (1, 5). Packaged rose plants are usually displayed for retail at ambient conditions up to 4 weeks before they are discarded or sold (personal observation). During this time they may encounter elevated temperatures and drying conditions. The effects of various temperatures and relative humidities encountered during storage and retail marketing on roses are not well documented.

In our previous study (Chapter 1), we saw a marked decline in regrowth quality following four weeks of simulated marketing at $23^{o}C$ on late-season, bare-root, packaged rose plants. Unwaxed roses exposed to $23^{o}C$ lost a significant amount of moisture during the four week simulated marketing period. It may also be assumed that plants lost moisture following planting in the field due to harsh but realistic conditions (Chapter 1). Since both the elevated holding temperature and the moisture loss would be expected to have a negative impact on late-season, bare-root, packaged rose plants, it was difficult to determine from our results the relative contribution of each to the decline in performance.

Waxing improved the performance of roses held at both 3° and 23°C (Chapter 1). Waxed plants held at 23°C lost less moisture during the holding period than plants without wax, yet still performed pooly after planting. Waxed plants held at 3°C did not have a significantly higher moisture content after four weeks, yet performed significantly better after planting compared to unwaxed plants. Moisture content was not monitored after planting in the field.

Our first objective was to determine the influence of temperature during simulated marketing on regrowth performance while minimizing the potential of water stress both during the holding period and during the regrowth period. Secondly we attempted to impose different levels of moisture stress while roses were held at 20°C for four weeks prior to planting. In addition, we tried to determine whether waxing the canes could have a beneficial effect other than that of a physical barrier to moisture loss.

MATERIALS AND METHODS

General Handling. Rose plants (Rosa) of previous unknown origin of the cultivars 'Femme' and 'Hotel Hershey' were taken from commercial refrigerated storage (1-3^{o}C) on April 29, 1986. The plants were disbudded as necessary, top pruned to 16 inches and root pruned to 12 inches; the roots were wrapped with moistened peat and packaged in plastic that was tied near the crown. The crown and canes of half of each cultivar were dipped in hot wax (80^{o}C). The remaining plants were left untreated. Controls were planted the day after treatment in the greenhouse under shade cloth and mist until growth resumed. The temperature in the greenhouse ranged from 18 to 21^{o}C and the relative humidity was in the range of 65 to 70%.

Temperature. The plants were then packed in large cardboad boxes, 16 plants to a box as follows: 4 'Femme' with untreated canes, 4 'Femme' with waxed canes, 4 'Hotel Hershey' with untreated canes, and 4 'Hotel Hershey' with waxed canes. The canes were well covered with moistened cedar shingle tow to minimize moisture loss. The boxes were then placed inside of large 6-mil polyethylele bags and placed in 0, 10, 20, or 30^{o} C (+/-2^{o}C) for two or four weeks. Relative humidity inside of the packages was assumed to be near 100%.

Before temperature treatment, each plant was sampled for moisture, soluble sugars and starch content by removing one cane and one root from each plant. The soluable sugars sample was taken from two sections of the cane and the remainder of the cane was used for moisture content determination. Moisture content was determined on a fresh weight/dry weight basis. Plants were removed from storage after 2 or 4 weeks, sampled again for moisture, soluable sugar and starch analysis, and planted in the greenhouse under shade cloth and intermittent mist. Regrowth was observed by counting the number of breaks, and measuring total growth per week for six weeks.

The data were analyzed as a completely randomized 3- or 4-way analysis of variance with four plants per treatment.

Moisture loss. After removal from commercial storage and processing as decribed above, rose plants were packed in cardboard boxes sealed with 6-mil polyethylene, cardboard boxes sealed with 6-mil perforated polyethylene, cardboard boxes, or crates (no package). Sixteen plants were used per package as follows: 4 'Femme' with untreated canes, 4 'Femme' with waxed canes, 4 'Hotel Hershey' with untreated canes, and 4 'Hotel Hershey' with waxed canes. All treatments were placed at 20^{o}C for four weeks. Before being packaged, each plant was sampled for moisture content by sampling one cane and one root from each plant. Moisture content was determined on a percent fresh weight basis.

Plants were removed from storage after four weeks and sampled again for moisture content and planted in the greenhouse under shade cloth and intermittent mist until growth resumed. Regrowth was observed by counting the number of breaks, and measuring total growth per week for six weeks.

The data were analyzed as a completely randomized 3-way analysis of variance with four plants per treatment.

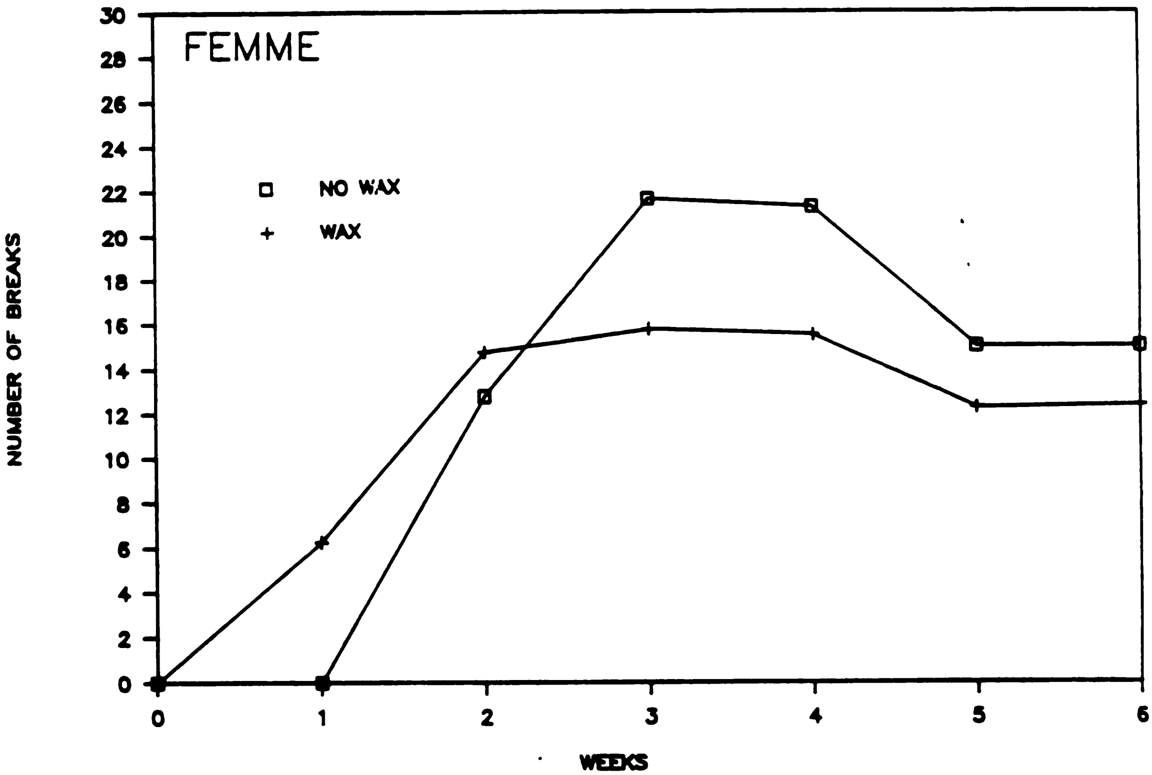
RESULTS

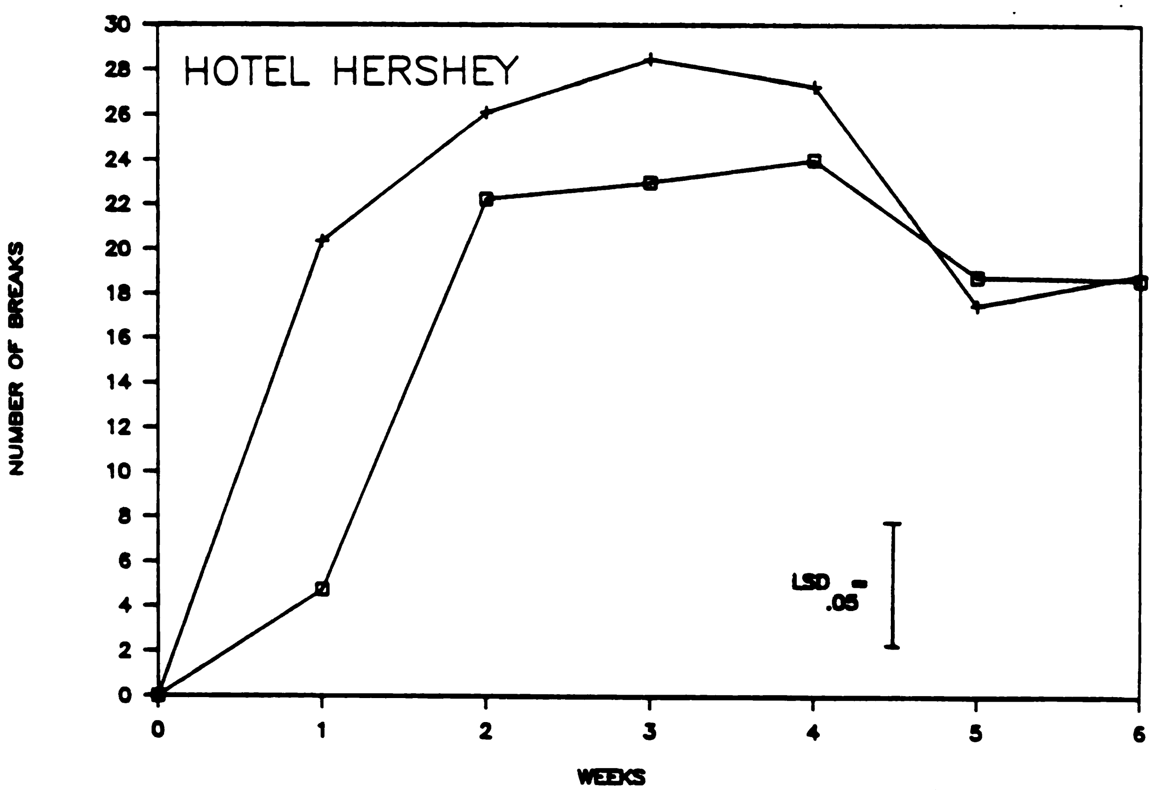
Initial moisture content. The initial moisture content of unwaxed plants was 59% ($LSD_{.05}$=1.9) for both cultivars. Assuming moisture content to be equivlent between waxed and unwaxed canes, the weight of the wax was calculated to be about 28% of dry cane weight for Femme and about 40% of the dry cane weight for Hotel Hershey (Appendix A). Femme had a slightly higher initial moisture content in the roots (57%) than Hotel Hershey (54%, $LSD_{.05}$=2.4).

Regrowth of controls. When planted one day following removal from storage and treatment with wax, rose plants of both cultivars initiated significantly more breaks than the unwaxed rose plants by the end of the first week of regrowth (Figure 2.1). This effect was less pronounced in subsequent regrowth weeks for Hotel Hershey. During weeks three and four of the regrowth period, there was a slight increase in number of breaks for the unwaxed Femme plants. There was a consistant decrease in number of breaks between weeks four through six due to death of some of the breaks. Wax did not appear to influence the death of breaks during this period (Figure 2.1).

Without exception, waxed roses of both cultivars had

Figure 2.1. Number of breaks during six weeks regrowth in the greenhouse for waxed and unwaxed roses of the cultivars 'Femme' and 'Hotel Hershey'. Plants were waxed one day prior to potting and regrowth in the greenhouse.


FEMME
NO WAX
WAX
NUMBER OF BREAKS
WEEKS


HOTEL HERSHEY
LSD .05 =
NUMBER OF BREAKS
WEEKS

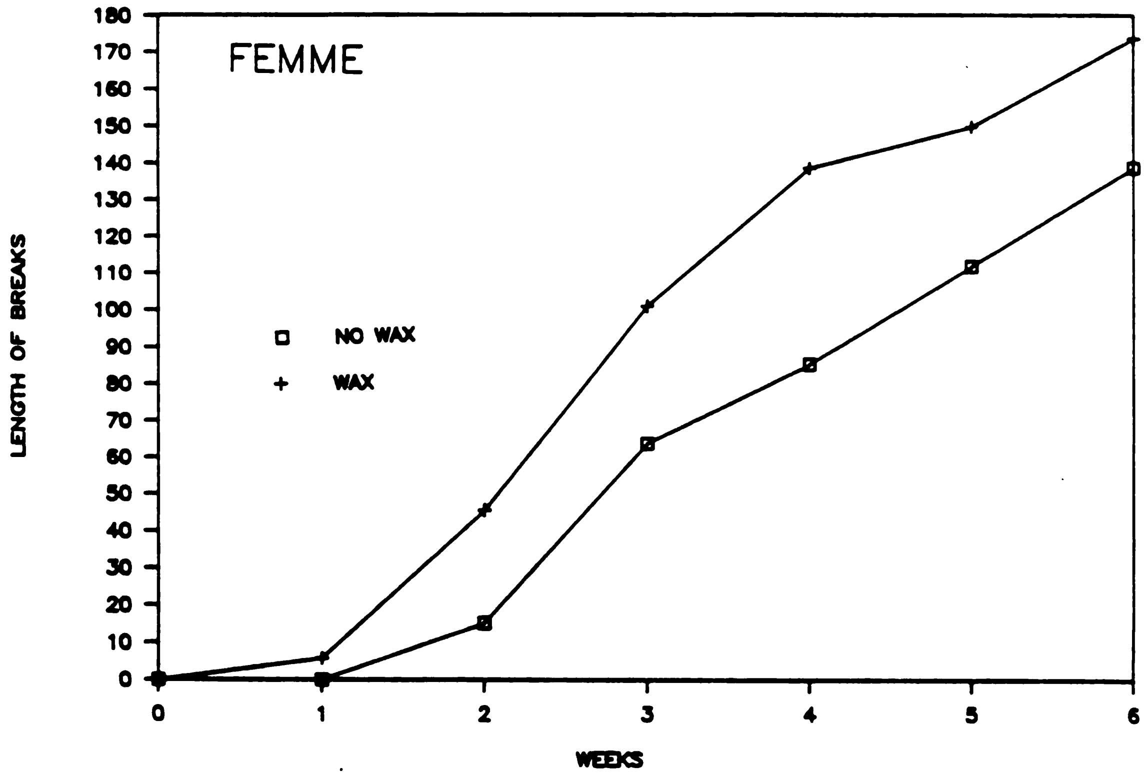
greater total length of canes (Figure 2.2) and length per cane (Figure 2.3) than unwaxed plants through the six weeks of regrowth. Femme had more total cane length at the end of the regrowth period than Hotel Hershey (Figure 2.2). The length per break on waxed Femme plants was about 47% longer than on the unwaxed plants after six weeks of regrowth. While this effect was consistent in Hotel Hershey, the difference was much smaller (ca. 15%).

Temperature Treatments. After the temperature treatments were imposed, the only roses that lost significant moisture were unwaxed plants held for four weeks independent of temperature (Table 2.1). Waxed roses lost virtually no moisture as compared to roses planted immediately. Moisture content did not vary with cultivar or holding temperature (data not shown). Moisture content of the roots did not change and was essentially the same as the roses planted immediately.

Plants held at 0°C and 30°C initiated almost no breaks during the holding period independent of duration, while those at 10°C and 20°C initiated about two breaks per plant (Figure 2.4). Femme initiated more breaks at 20°C while Hotel Hershey initiated more breaks at 10°C (Table 2.2).

At the first week of regrowth, Hotel Hershey had nearly twice as many breaks as Femme (Table 2.3). This cultivar difference disappeared by the second week (results not shown). After one week of regrowth, plants removed from 0°C or 10°C had several times more breaks than plants at 20°C or

Figure 2.2. Length of breaks during six weeks regrowth in the greenhouse for waxed and unwaxed roses of the cultivars 'Femme' and 'Hotel Herhsey'. Plants were waxed one day prior to potting and regrowth in the greenhouse.


FEMME
NO WAX
WAX
LENGTH OF BREAKS
WEEKS
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
0 1 2 3 4 5 6

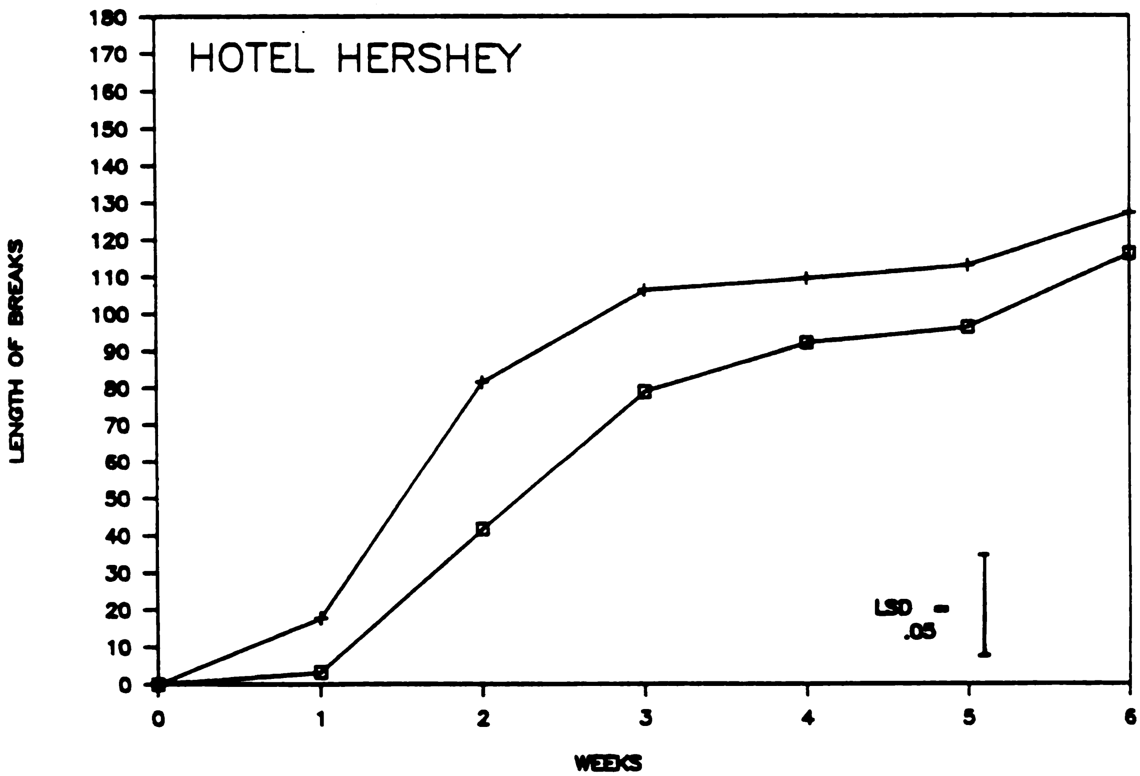
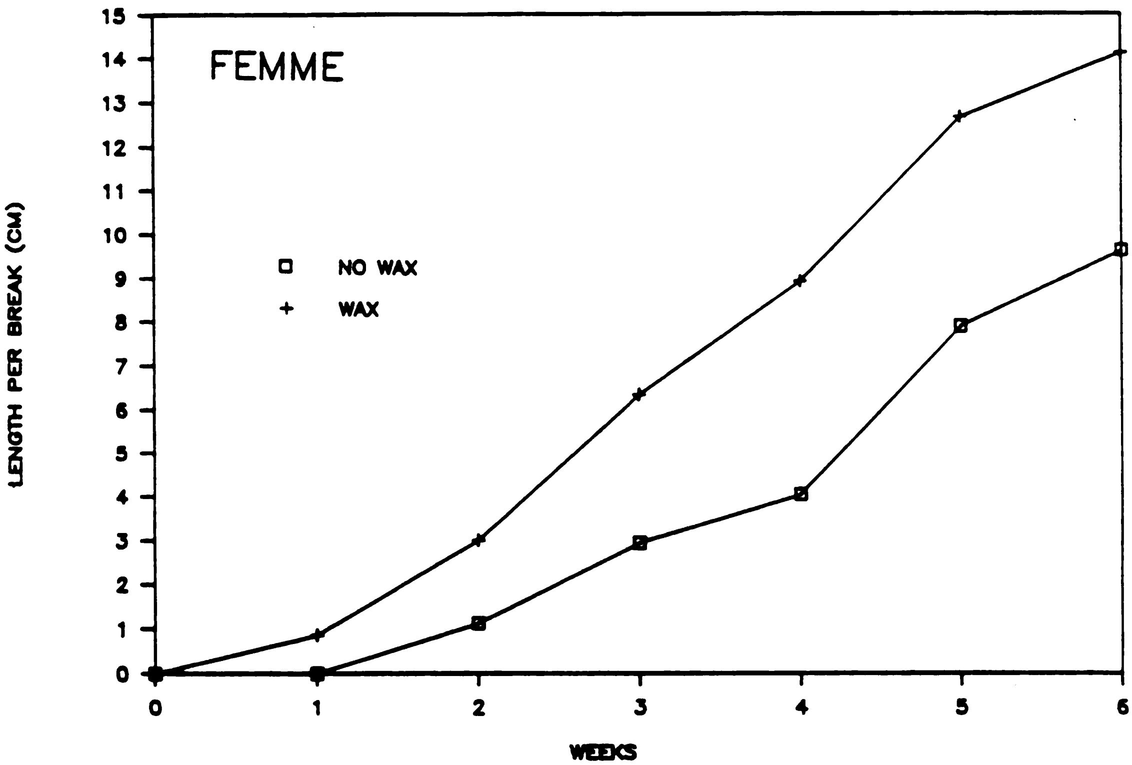

HOTEL HERSHEY
LSD =
.05
LENGTH OF BREAKS
WEEKS
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
0 1 2 3 4 5 6

Figure 2.3. Length per break during six weeks regrowth in the greenhouse for waxed and unwaxed roses of the cultivars 'Femme' and 'Hotel Hershey'. Plants were waxed one day prior to potting and regrowth in the greenhouse.


FEMME
NO WAX
WAX
LENGTH PER BREAK (CM)
WEEKS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

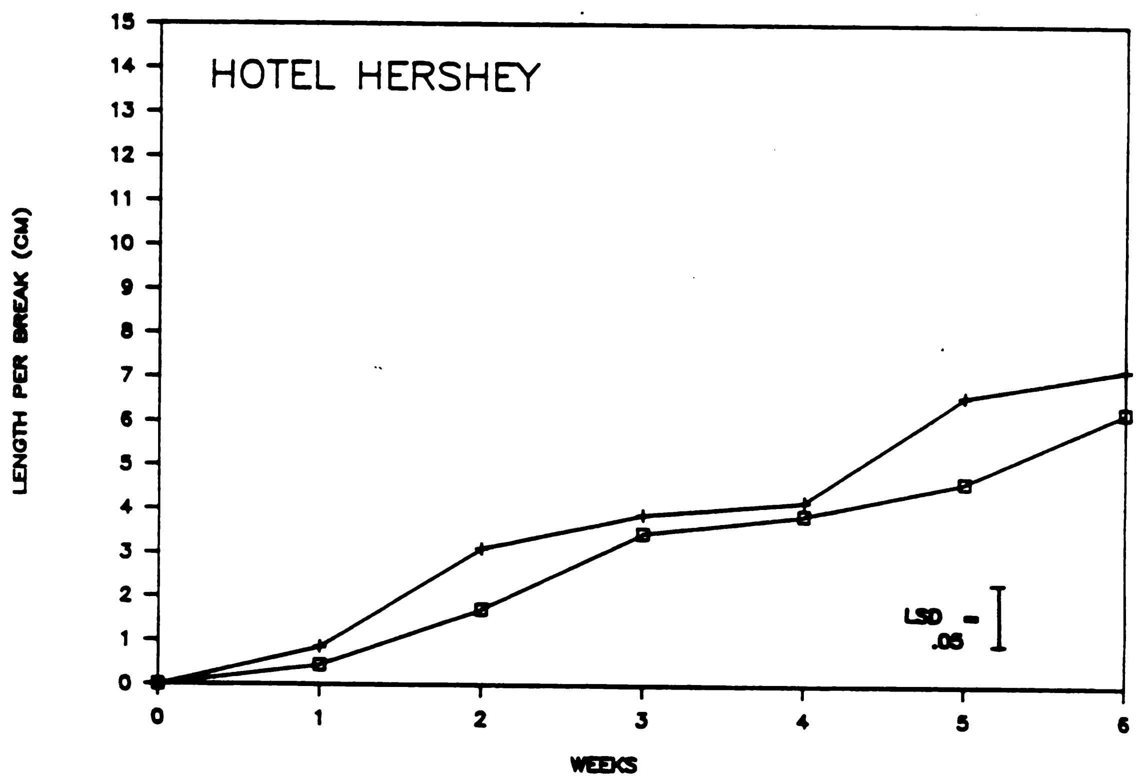
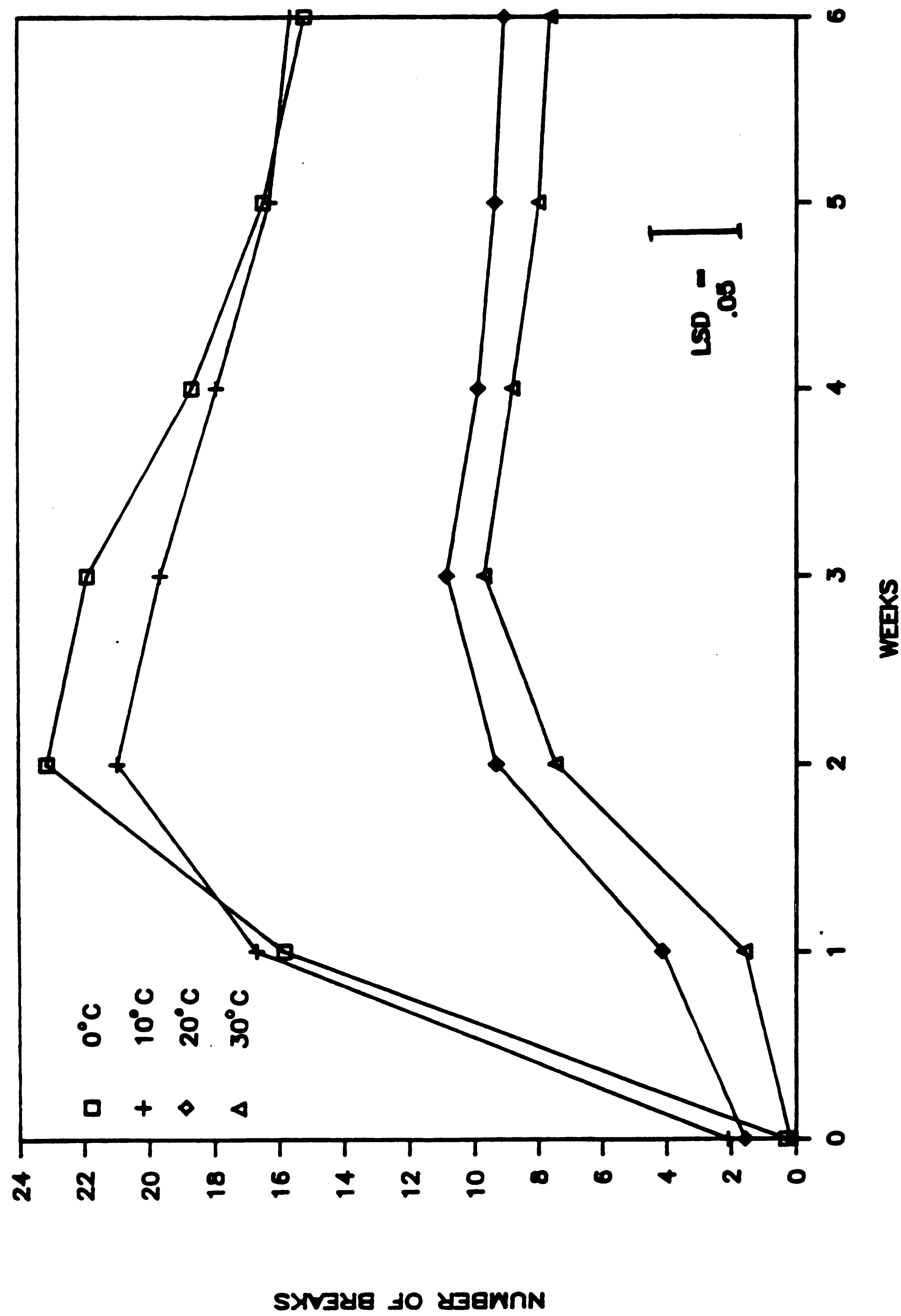

HOTEL HERSHEY
LSD = .05
LENGTH PER BREAK (CM)
WEEKS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Table 2.1. Effect of holding duration and waxing on percent moisture content of rose canes upon removal from temperature treatments.

Holding Duration	Moisture Barrier No Wax	Wax
Two weeks	61.6	60.8
Four weeks	57.1	60.2

$LSD_{.05}$ = 2.2 for all comparisons.

Figure 2.4. Main effect of temperature on number of breaks during the subsequent six week regrowth period in the greenhouse following treatments.



NUMBER OF BREAKS
WEEKS
0°C
10°C
20°C
30°C
LSD .05 =
0
2
4
6
8
10
12
14
16
18
20
22
24
0
1
2
3
4
5
6

Table 2.2. Number of breaks per plant upon removal from holding temperatures for two or four weeks for roses of the cultivars 'Femme' and 'Hotel Hershey'.

	Cultivar			
	'Femme'		'Hotel Hershey'	
	Holding Duration			
Temperature (C)	2 weeks	4 weeks	2 weeks	4 weeks
0	0.0	0.0	0.5	0.8
10	0.1	0.9	1.3	6.1
20	1.2	2.8	0.6	1.5
30	0.0	0.0	0.6	0.1

$LSD_{.05}$ = 1.5 for all comparisons.

Table 2.3. Number of breaks per plant after temperature treatment and one week regrowth in the greenhouse for roses of the cultivars 'Femme' and 'Hotel Hershey'.

	Cultivar	
Temperature (C)	'Femme'	'Hotel Hershey'
0	10.3	21.4
10	10.7	22.7
20	4.9	3.4
30	0.7	2.5

$LSD_{.05}$ = 3.9 for all comparisons.

30°C (Table 2.3; Figure 2.4). This trend continued through the entire six week regrowth period. The number of breaks generally peaked after 2 to 3 weeks regrowth then declined slightly over time (Figure 2.4). This effect was much more noticable following 0° and 10°C treatment then following 20° or 30°C treatment (Figure 2.4).

Following the second week of regrowth, it was evident that with longer duration of holding, there was a decline in the number of breaks independent of other treatment effects at 20° and 30°C (Figure 2.5). There were no significant interactions between holding duration and temperature during the regrowth period.

Waxed plants from the 10°C treatment had consistantly more breaks during regrowth than the unwaxed plants (Figure 2.6). Following the 20° and 30°C holding temperatures, waxing did not increase the number of observed breaks (Figure 2.6).

Total length of breaks after six weeks regrowth was greatest for plants from the 10°C treatment, followed by 0°, 20° and 30°C for both varieties (Figure 2.7). Femme and Hotel Hershey responded similarly in total length during weeks three through six, although the magnitude of difference between temperatures was greater for Femme. Hotel Hershey generated more new cane growth after holding at 0° and 10°C than Femme for the first two weeks of regrowth. Initially, more total cane growth was observed after removal from 20°C while the shortest breaks were seen

Figure 2.5. Effect of holding duration and temperature on number of breaks during the subsequent regrowth period in the greenhouse.

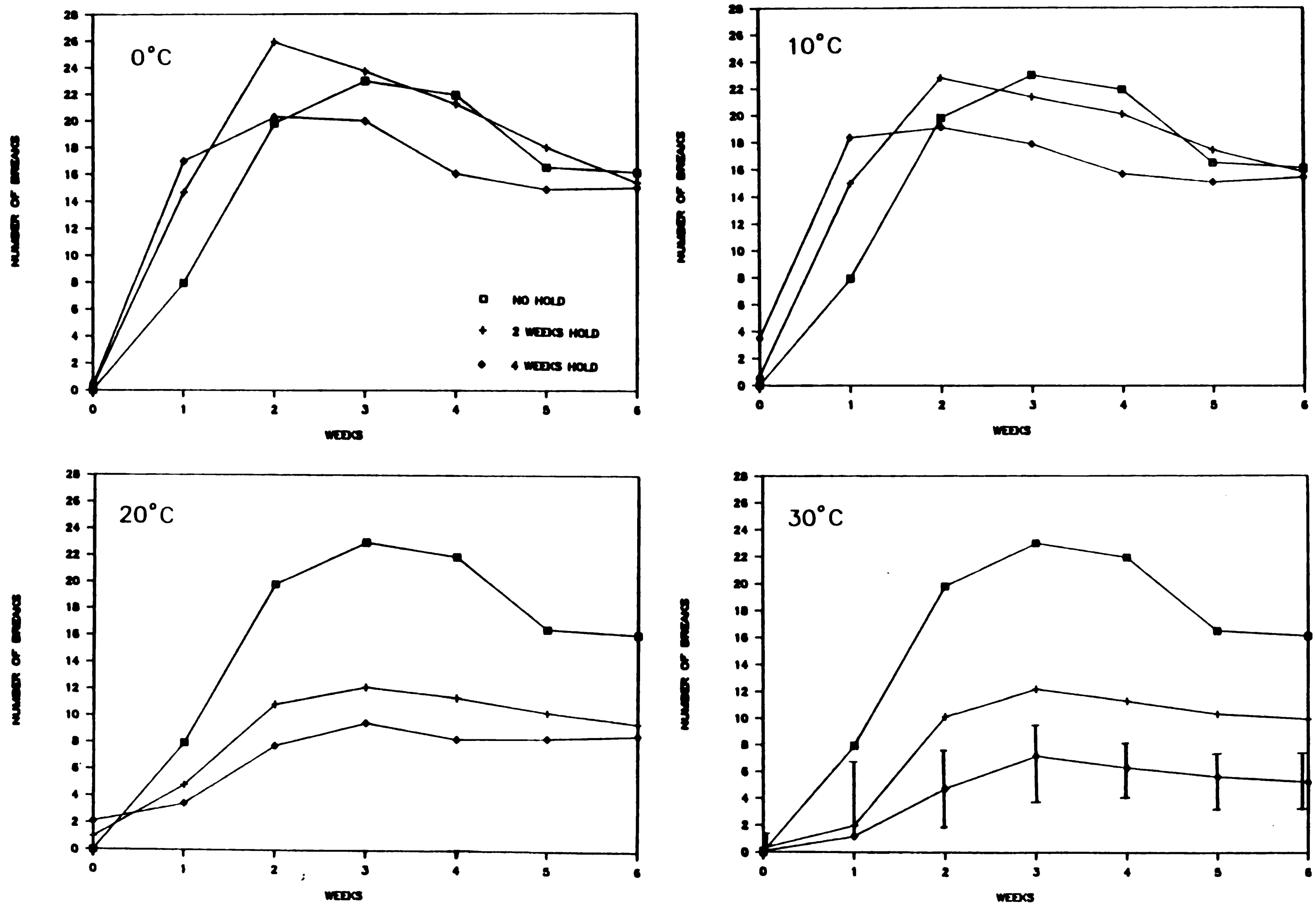

0°C
10°C
20°C
30°C
NUMBER OF BREAKS
WEEKS
NO HOLD
2 WEEKS HOLD
4 WEEKS HOLD

Figure 2.6. Effect of waxing and holding at various temperatures on number of breaks during the subsequent regrowth period.

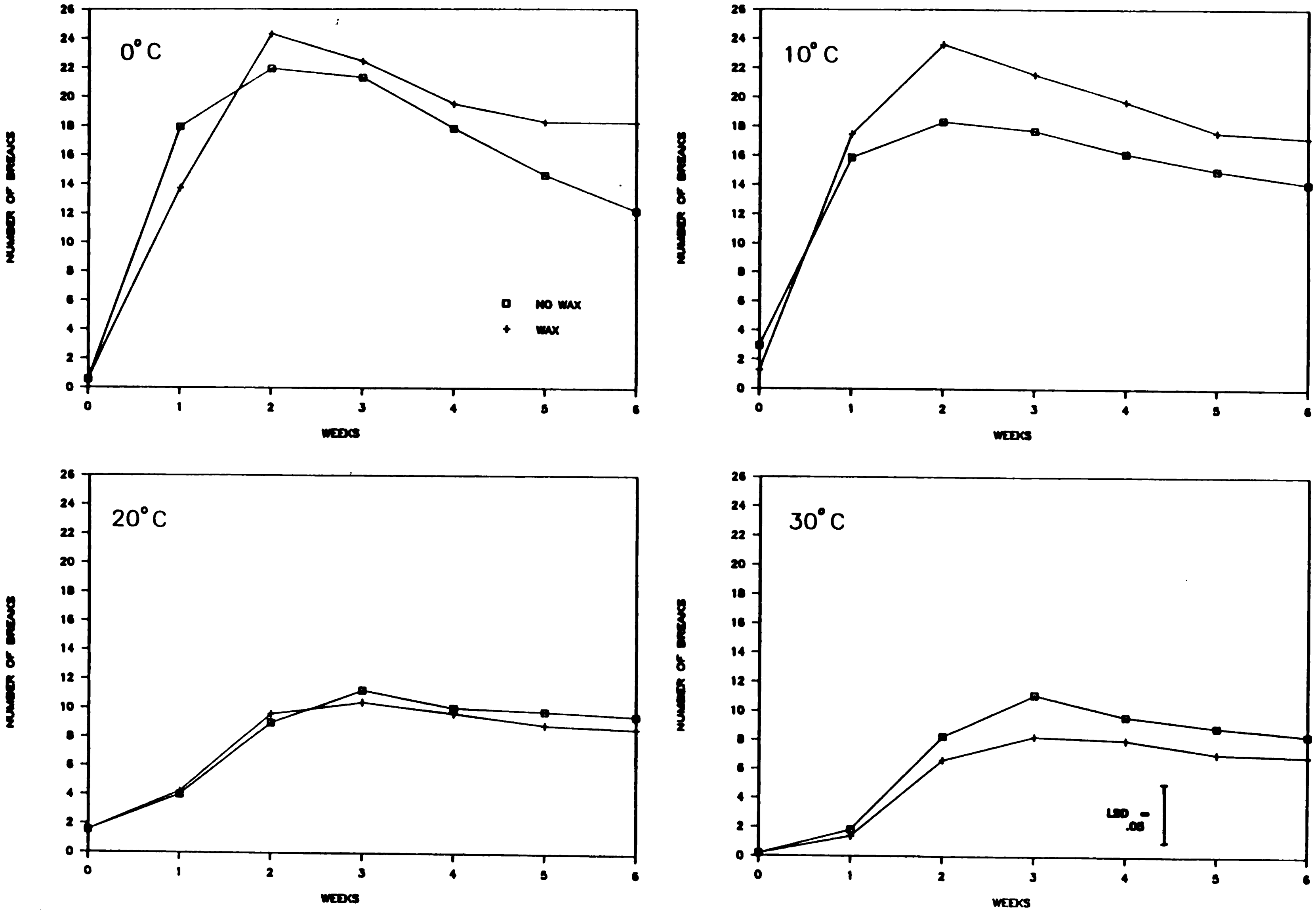
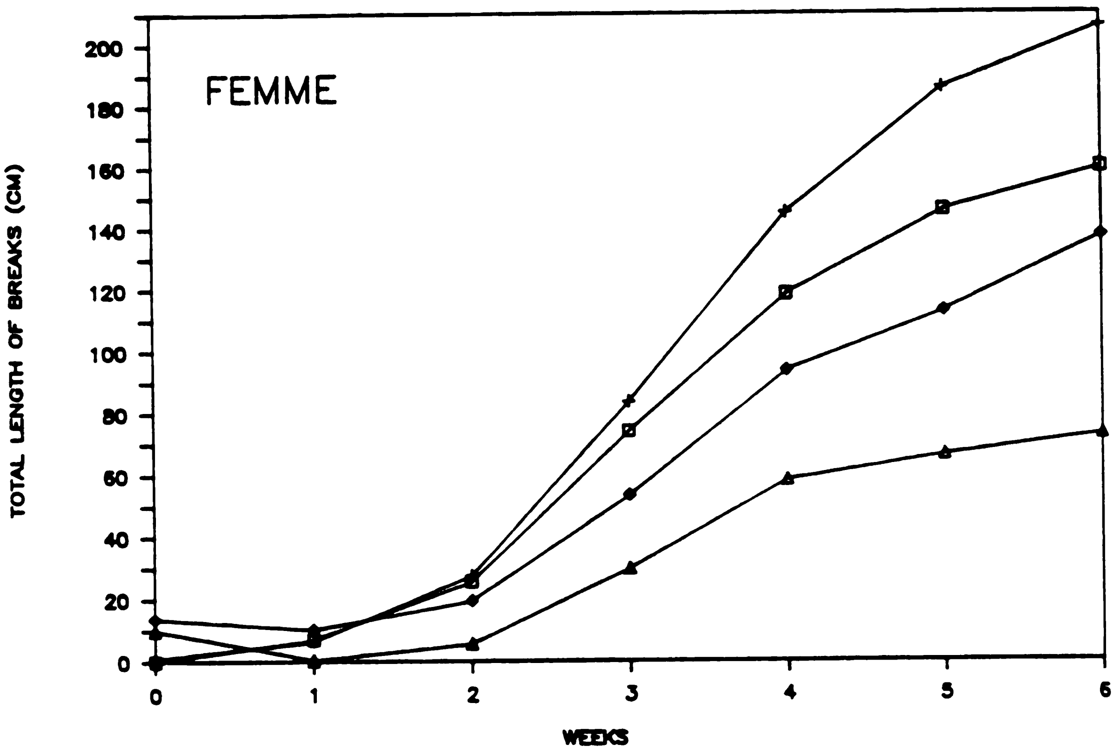
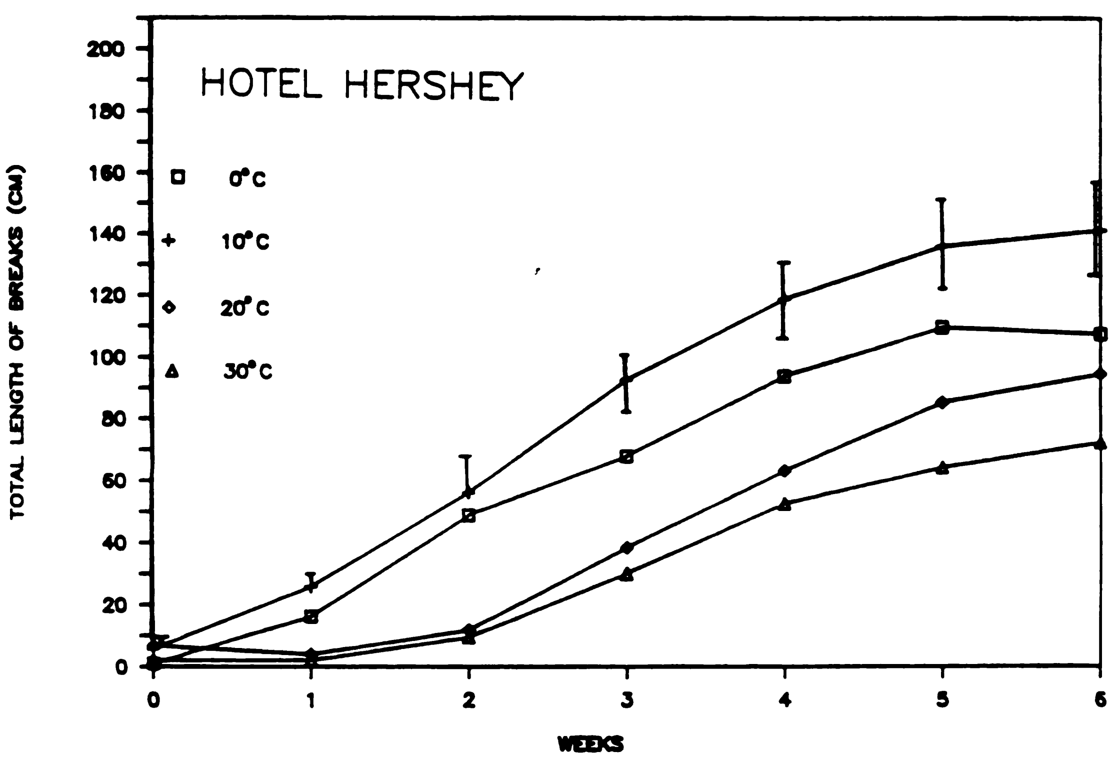

0° C
10° C
20° C
30° C
NUMBER OF BREAKS
WEEKS
NO WAX
WAX
LSD =
.05
0
1
2
3
4
5
6
2
4
6
8
10
12
14
16
18
20
22
24
26

Figure 2.7. Effect of holding temperature on length of breaks during the subsequent regrowth period for roses of the cultivars 'Femme' and 'Hotel Hershey'.


FEMME
TOTAL LENGTH OF BREAKS (CM)
0
20
40
60
80
100
120
140
160
180
200
0
1
2
3
4
5
6
WEEKS


HOTEL HERSHEY
TOTAL LENGTH OF BREAKS (CM)
0°C
10°C
20°C
30°C
0
20
40
60
80
100
120
140
160
180
200
0
1
2
3
4
5
6
WEEKS

on the plants removed from 0° and 30°C (Figure 2.7). Femme initiated more cane growth following the 20°C treatment while Hotel Hershey initiated almost equal cane growth following both 10° and 20°C (Table 2.4). The waxed plants removed from 20°C after holding four weeks had more than twice the cane length of the unwaxed plants of the same treatment and more than six times the cane length of the plants held at 20°C for two weeks (Table 2.5).

Roses held for two or four weeks at 20° or 30°C had somewhat less total regrowth than roses planted immediately after storage and packaging independent of temperature, barrier or cultivar for regrowth weeks two through six (Figure 2.8). After one week regrowth, Femme plants held four weeks had more growth following treatment at 0°, 10° and 20°C than those held for two weeks (Table 2.6). Hotel Hershey plants held four weeks at 10°C had over twice the length of new growth as those held two weeks at 10°C (Table 2.6).

There was no difference in length per break for the 0°, 10° and 30°C temperatures (Figure 2.9). Following four weeks holding at 20°C, Femme plants had more than twice as much length per break than other temperature treatments. A similar trend was observed for roses held for two weeks (Figure 2.9). The length per break for Hotel Hershey was approximately the same length regardless of the holding temperature or duration (Figure 2.10). Upon removal from 20°C for four weeks, both cultivars had a few very long

Table 2.4. Total length of breaks per plant upon removal from holding temperatures for both rose cultivars.

	Cultivar	
Temperature (C)	'Femme'	'Hotel Hershey'
0	0.0	1.1
10	0.9	5.8
20	13.7	6.7
30	0.0	2.1

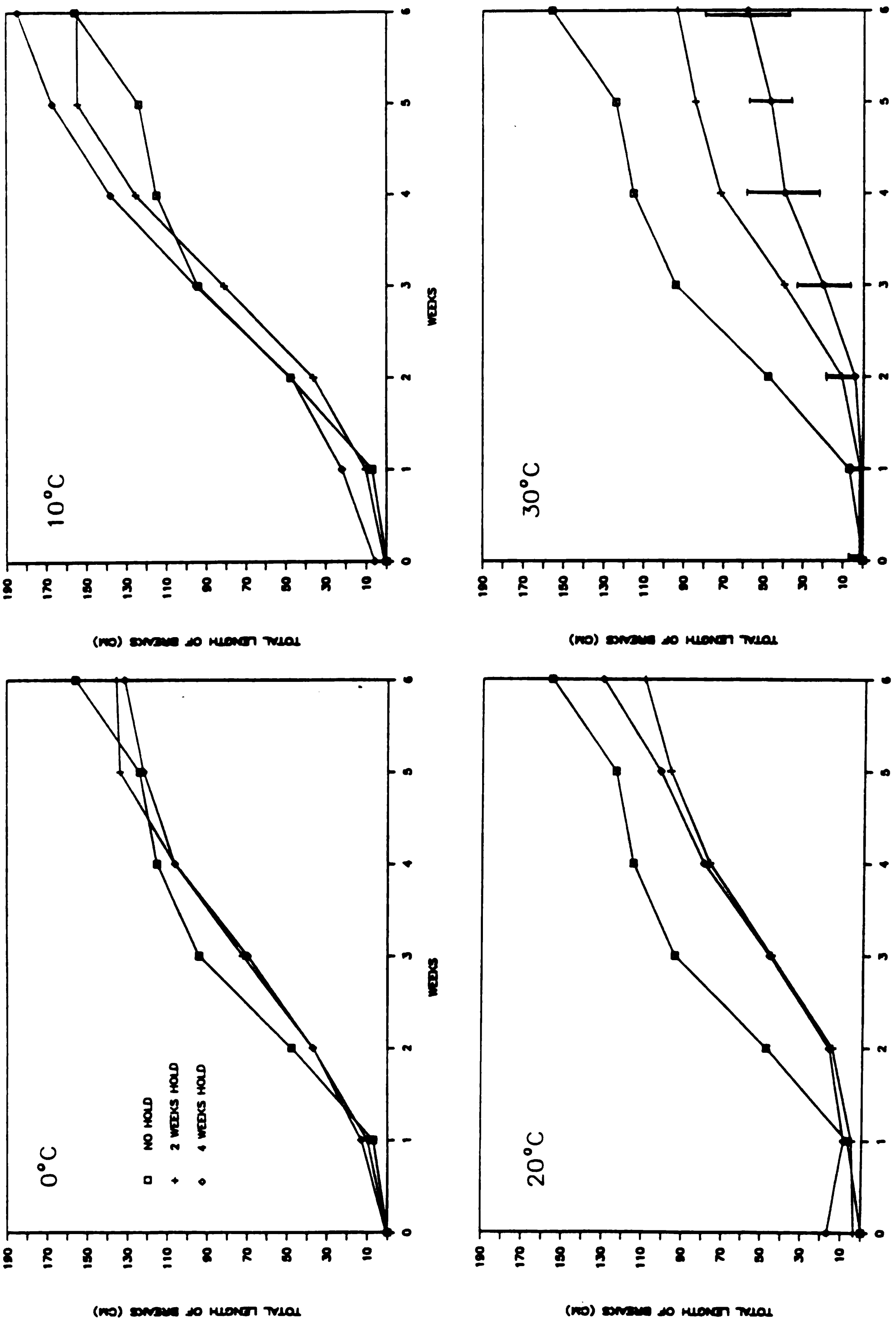
$LSD_{.05}$ = 2.3 for all comparisons.

Table 2.5. Total length of breaks per plant upon removal from holding for two or four weeks for waxed and unwaxed plants of both cultivars.

		Moisture Barrier	
	Temperature (C)	No Wax	Wax
2 weeks Holding duration	0	0.3	0.3
	10	1.9	0.3
	20	4.5	2.9
	30	1.0	2.6
4 weeks Holding duration	0	1.5	0.0
	10	6.6	4.7
	20	10.0	23.4
	30	0.6	0.0

$LSD_{.05}$ = 6.5 for all comparisons.

Figure 2.8. Effect of holding duration and temperature on length of breaks during the subsequent regrowth period in the greenhouse.



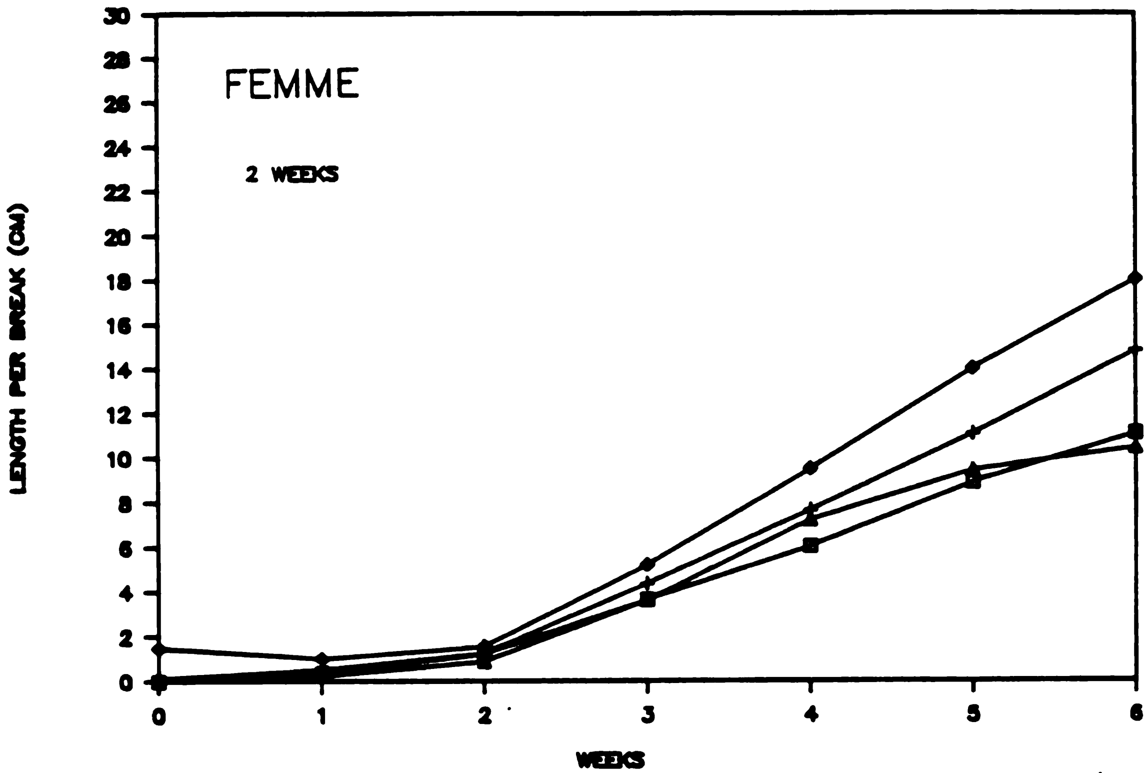
0°C
10°C
20°C
30°C
NO HOLD
2 WEEKS HOLD
4 WEEKS HOLD
WEEKS
TOTAL LENGTH OF BREAKS (CM)

Table 2.6. Total length of breaks per plant after holding for two or four weeks at various temperatures and one week regrowth in the greenhouse for both rose cultivars.

	Temperature (C)	Cultivar 'Femme'	'Hotel Hershey'
2 weeks Holding duration	0	3.9	16.2
	10	5.1	15.6
	20	6.1	4.3
	30	0.6	2.8
4 weeks Holding duration	0	10.0	16.1
	10	7.9	36.4
	20	14.2	3.8
	30	0.2	1.4

$LSD_{.05}$ = 5.7 for all comparisons.

Figure 2.9. Effect of holding duration and temperature on length per break during the subsequent regrowth period for 'Femme'.


FEMME
2 WEEKS
LENGTH PER BREAK (CM)
WEEKS
0
1
2
3
4
5
6
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0

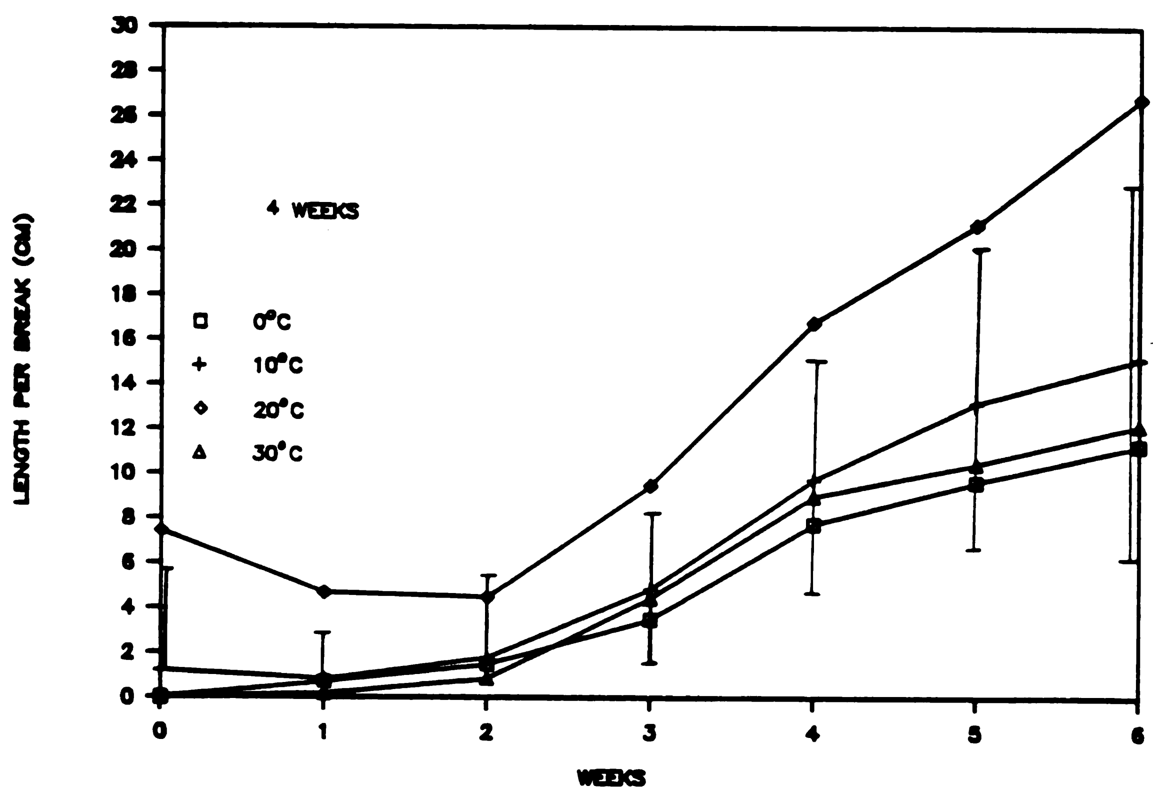
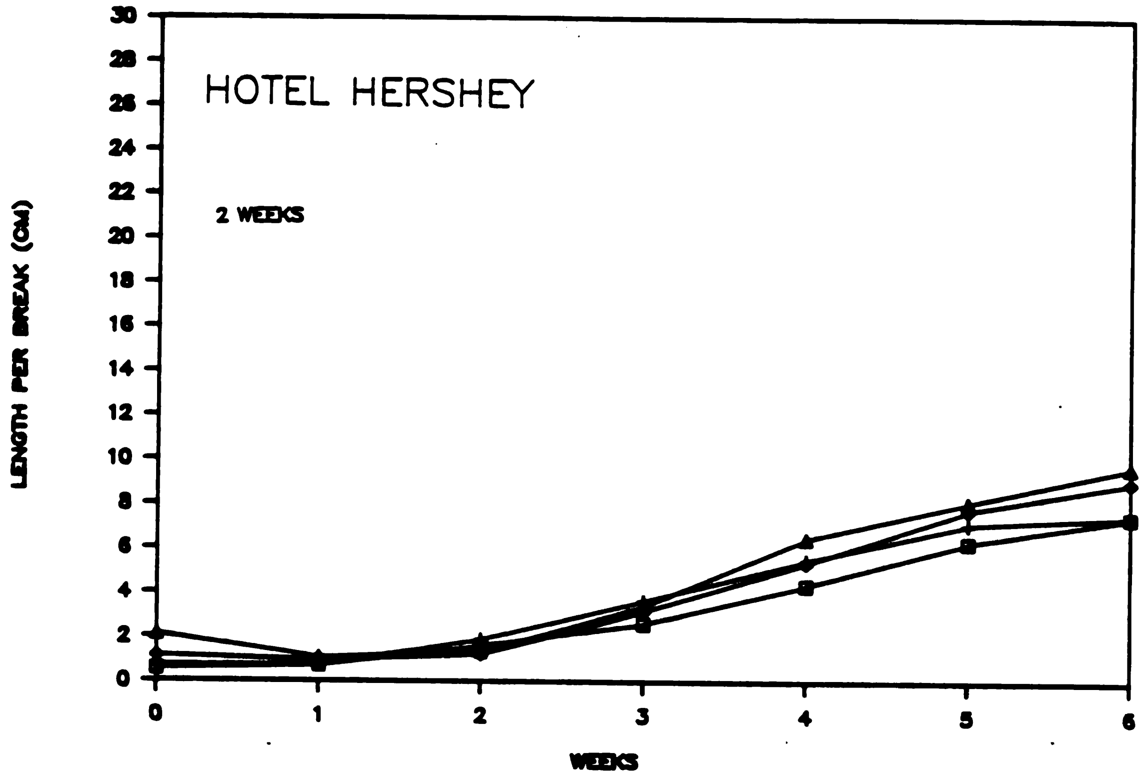
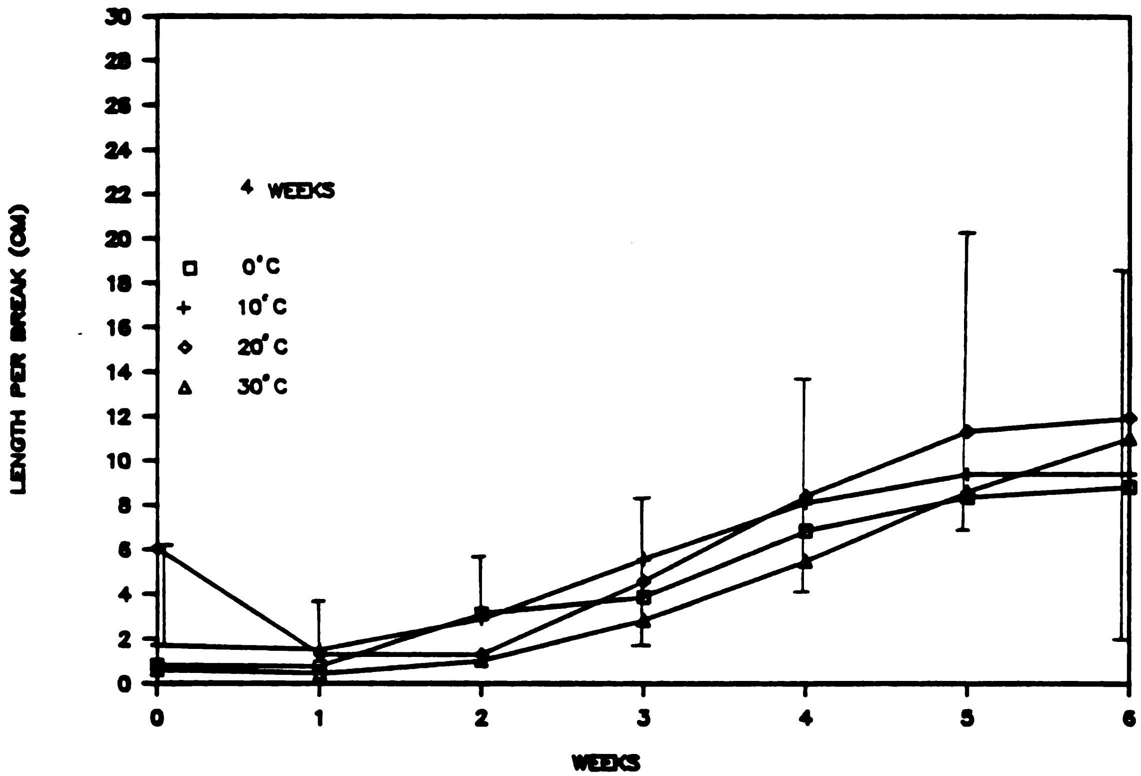

4 WEEKS
0°C
10°C
20°C
30°C
LENGTH PER BREAK (CM)
WEEKS
0
1
2
3
4
5
6
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0

Figure 2.10. Effect of holding duration and temperature on length per break during the subsequent regrowth period for 'Hotel Hershey'.


HOTEL HERSHEY
2 WEEKS
LENGTH PER BREAK (CM)
WEEKS
0
1
2
3
4
5
6
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0


4 WEEKS
0°C
10°C
20°C
30°C
LENGTH PER BREAK (CM)
WEEKS
0
1
2
3
4
5
6
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0

breaks. Waxing did not significantly affect the length per break.

Moisture treatments. After removing from holding for four weeks at 20°C in various packages, unwaxed plants had a significantly lower percent cane moisture content (55%) than waxed plants (60%, $LSD_{.05}$=1.7) independant of package and variety. This difference was due almost entirely to unwaxed roses held in air (Table 2.7). In addition, none of the treatments lost a significant amount of moisture from the roots except the plants held in air for four weeks without wax (Table 2.7). Femme had a higher moisture content in the roots (59%) than Hotel Hershey (55%) similar to the controls planted immediately.

At the end of the four week holding period, unwaxed plants held in air for four weeks had absolutely no growth while all other treatments had initiated regrowth with average total length and length per cane of 85 cm and 13 cm respectively (Figure 2.11, Table 2.8). Femme had almost twice the length of breaks (88 cm) and length per break (14 cm) upon removal from holding compared to Hotel Hershey (48 cm and 8 cm). Waxed plants had more length per break after holding (13 cm) than unwaxed plants (9 cm). Some of the etiolated growth initiated during holding subsequently died after planting in the greenhouse (data not shown).

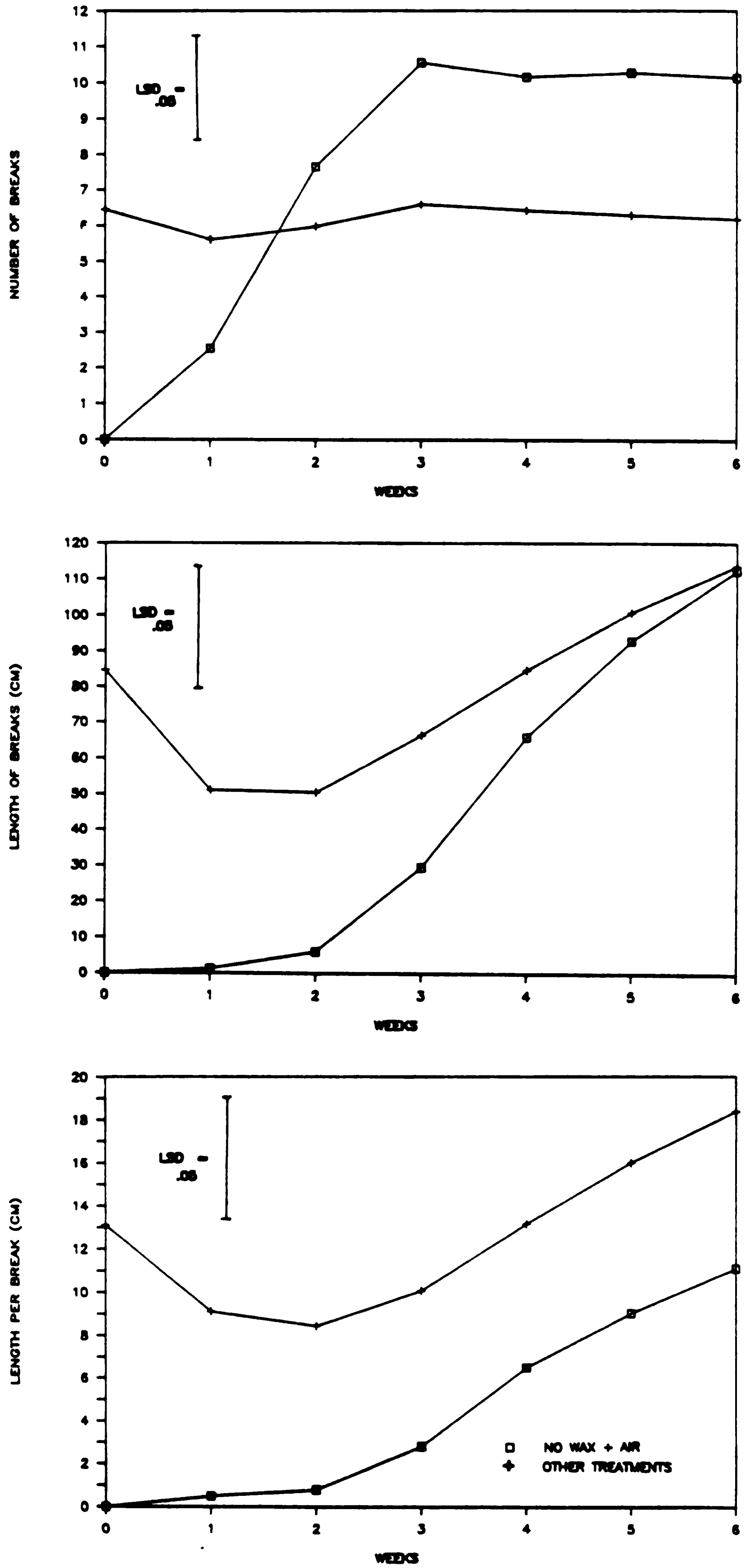
During the subsequent regrowth period, the unwaxed plants previously held in air were slower to initiate

Table 2.7. Percent moisture content of canes and roots upon removal from holding treatments in various packaging materials for waxed and unwaxed plants of both cultivars.

	No wax		Wax	
Packaging Treatment	Canes	Roots	Canes	Roots
Air	43.4	48.1	58.3	59.3
Cardboard	57.9	57.9	60.5	58.5
Perforated Polyethylene	60.7	59.7	60.9	57.0
Polyethylene	59.5	59.3	61.0	58.4

$LSD_{.05}$ = 5.7 for all comparisons.

Figure 2.11. Number of breaks (a), total length of breaks (b) and length per break (c) for plants unwaxed and held in air versus all other treatment combinations during the subsequent regrowth period in the greenhouse.



LSD .05
NUMBER OF BREAKS
WEEKS
LSD .05
LENGTH OF BREAKS (CM)
WEEKS
LSD .05
LENGTH PER BREAK (CM)
NO WAX + AIR
OTHER TREATMENTS
WEEKS

Table 2.8. Percentage of plants untreated with wax and held in air to breaks bud each weeks versus all other treatments combined. The data was not analyzed statistically.

Packaging Treatment / Week	0	1	2	3	4	5
No wax plus air	0	38	88	88	88	100
All other treatments combined	100	100	100	100	100	100

regrowth (Figure 2.11). Only after the fifth week in the greenhouse had all of the unwaxed plus air-treated plants initiated growth (Table 2.8). At the end of the observation period, these plants had more but shorter breaks than the other treatments, though the total length was the same (Figure 2.11, Table 2.10). Overall, Femme had 24% more total growth and 21% more length per break than Hotel Hershey (data not shown).

DISCUSSION

The results of this research clearly demonstrate a direct deleterious effect of elevated marketing temperatures on the subsequent regrowth of late-season, packaged roses even when there was no detectable change in the moisture content of the canes or roots. Rose plants held as little as two weeks at 20° or 30°C initiated growth more slowly, developed fewer breaks (Figure 2.5), and had less total regrowth after six weeks (Figure 2.8) than rose held at 0° or 10°C. It should be noted that the moisture content of unwaxed roses held four weeks decreased about 3% regardless of holding temperature, but this was not associated with a decline in regrowth quality.

Although various levels of moisture stress were imposed on roses held at 20°C in the second series of experiments, only nonwaxed roses held in air lost a significant amount of moisture. This loss was approximately 15% from the controls and caused a further decline in regrowth quality compared to roses held at 20°C without moisture stress (Figure 2.11). When compared to results obtained in the field study (Chapter 1), it is highly likely that these roses would have had poor survival after the first winter in the field.

The observation that other moisture stress levels did not alter cane moisture content could be related to the ability of the roots to extract moisture from the moistened packing material. It would be interesting to measure the moisture content of the media during simulated display to determine how much water can be transported. Note, however, that in no case did alleviation of water stress correct the regrowth problems associated with elevated simulated marketing temperatures.

Waxing significantly enhanced the rate of bud break when roses were planted one day after treatment (Figure 2.1). Waxed roses planted immediately also had consistently greater length per break and total cane length (Figures 2.2, 2.3). In all experiments, plants were grown under shade cloth with intermittent mist until regrowth was intiated in the greenhouse. Thus, this immediate effect of wax may not be associated with moisture relations. It is possible that there is a direct effect of temperature on bud break. Under the contitions of this experiments, little or no effect of waxing was noted after two or four weeks at any of the four temperatures tested when moisture stress was minimized (Figure 2.6). When held in air at 20°C, waxing did prevent the loss of moisture compared to unwaxed plants and thus, prevented a decline in regrowth performance (Table 2.7). From these results, the beneficial effect of waxing the first year (Chapter 1) might have been due to protection from desiccation after planting.

Plants held at 0°C remained relatively dormant while those at 10° and 20°C had rapid, etiolated growth (Table 2.2). Hotel Hershey plants held at 10°C had the most breaks upon removal from holding and subsequently had the most total growth at the end of the six week regrowth period

(Table 2.2, Figure 2.7). Plants at 20^{o}C had a few particularily long etiolated breaks form during holding. Plants at 30^{o}C actually had fewer etiolated breaks probably due to high temperature inhibition or secondary dormancy imposed by the high temperature.

Though initiating growth while still packaged may not be beneficial to the rose plants, customers may prefer to buy their rose plants this way (3). A 1958 survey by Mahlstede reported that in general, customers preferred these plants that had begun regrowth assuming these plants were "alive and healthy" (3). Unfortunately, this often etiolated growth may deplete stored food reserves, increase transpiration and will probably die following planting (Chapter 1). However, in this study, breaks initiated during storage did not necessarily reduce regrowth quality when regrowth took place in the greenhouse conditions (Figures 2.6).

Upon removal from commercial storage in the first study (Chapter 1), Femme was observed to have fewer canes of smaller diameter than the other three cultivars and this was associated with a poorer regrowth performance. In the current study, Hotel Hershey had fewer canes of smaller diameter than Femme and had weaker regrowth performance. Thus, cultivar differences noted in these studies may actually be attributed to production conditions and overall plant vigor at the time of harvest.

Overall, the combined results of both studies clearly indicate that prolonged exposure of packaged roses to temperature of 20°C and above is deleterious to subsequent regrowth. We strongly recommend that retailers consider the use of refrigerated display areas. One option would be to use refrigerated cases such as those currently used for fresh vegetables. Although moisture loss is minimal at reduced temperature (Chapters 1 and 2), waxing may still be desirable to improve subsequent field performance. While waxing may prevent unavoidable moisture stress and improve field performance, it will not correct problems associated with elevated temperatures.

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APPENDIX

APPENDIX A

Percent water content was measured for waxed and unwaxed rose canes on a fresh weight/dry weight basis. Based on the assumption that all rose canes had about the same moisture content when removed from storage, the following shows how the weight of the wax can be calculated and corrected for on waxed canes. The correction factor for the weight of the wax calculated from the controls was used to determine the percent moisture content on a fresh weight basis for rose canes after treatments were imposed.

I. For convenience, the percent fresh weight measured for all unwaxed plants can be defined as:

$$a = (H_2O/FW) \qquad (1)$$

where H_2O is grams of water in the cane sample and FW is total fresh weight of cane.

By definition:

$$FW = H_2O + DW \qquad (2)$$

and

$$DW = FW - H_2O \qquad (3)$$

where DW is the dry weight in grams of the cane sample.

Dividing equation (2) by DW and rearranging yields:

$$\frac{H_2O}{DW} = \frac{FW}{DW} - 1 \qquad (4)$$

Substituting equation (3) into equation (4) and simplifying yields:

$$\frac{H_2O}{DW} = \frac{H_2O}{FW - H_2O} \qquad (5)$$

$$\frac{H_2O}{DW} = \frac{H_2O/FW}{1 - \frac{H_2O}{FW}} \qquad (6)$$

Substituting with equation (1):

$$\frac{H_2O}{DW} = \frac{a}{1 - a} \qquad (7)$$

Substituting with equation (4) and solving for $\frac{FW}{DW}$:

$$\frac{FW}{DW} = \frac{1}{1 - a} \qquad (8)$$

Thus, the relationship between water content to dry weight and fresh weight to dry weight can easily be calculated from the moisture content on a fresh weight basis by substituting values into equations (7) and (8).

II. For calculation of the weight of the wax, use data collected at the same time as unwaxed plants which yielded a value b, defined as grams of water divided by total weight for the waxed plants:

$$\text{let } b = \frac{H_2O}{FW + WAX} \qquad (9)$$

or

$$b = \frac{\frac{H_2O}{DW}}{\frac{FW}{DW} + \frac{WAX}{DW}} \qquad (10)$$

where WAX is the weight of the wax on the waxed cane sample.

Solving for $\frac{WAX}{DW}$:

$$\frac{WAX}{DW} = \frac{H_2O}{DW} \times \frac{1}{b} - \frac{FW}{DW} \qquad (11)$$

Substituting equations (7) and (8):

$$\frac{WAX}{DW} = \frac{a}{1-a} \times \frac{1}{b} - \frac{1}{1-a} \qquad (12)$$

or

$$c = \frac{WAX}{DW} = \frac{a - b}{(1-a)b} \qquad (13)$$

III. The constant c (wax/dry weight) can now be used to correct for the weight of the wax from the total weight of waxed canes.

Rearranging equation (10) and substituting with equation (13) yields:

$$\frac{H_2O}{DW} = \frac{b(c+1)}{1 - b} \qquad (14)$$

defining moisture content in the waxed canes on a dry weight basis.

Rearranging equation (2) yields:

$$\frac{FW}{H_2O} = \frac{DW}{H_2O} + 1 \qquad (15)$$

Substituting with equation (14) and solving for $\frac{H_2O}{FW}$ gives:

$$\frac{H_2O}{FW} = \frac{bc+b}{bc+1} \qquad (16)$$

Thus, the moisture content in waxed canes is defined on a fresh weight basis when the weight of the wax is removed.

IV. Example: Moisture content on a fresh weight basis for unwaxed canes upon removal from storage is 60% and moisture content on a fresh weight basis for waxed canes upon removal from storage is 55%.

Therefore,

$$a = .60$$

$$b = .55$$

and

$$c = \frac{WAX}{DW} = \frac{a - b}{(1-a)b} \qquad (13)$$

$$= \frac{.60 - .55}{(1-.60)(.55)}$$

$$= .2273$$

or, the weight of the wax is 22.73% of the moisture content on a fresh weight basis.

A waxed cane sample has an apparent water content of 52% four weeks after removal from storage and treatment.

if
$$\frac{H_2O}{DW} = \frac{bc + b}{bc + 1} \qquad (16)$$

then
$$= \frac{.52(.2273) + .52}{.52(.2273) + 1}$$

$$= .57$$

or, 57% moisture content on a fresh weight basis after the correction is made for the weight of the wax.