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Incidence and Severity of Chilling Induced Internal Browning of Waxed 'Smooth Cayenne' Pineapple[1]

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Abstract. **Waxing the fruit and crown of fresh pineapple [*Ananas comosus* (L.) Merr.] with a 20% v/v paraffin-polyethylene:water mixture reduced the incidence and severity of internal browning caused by chilling injury to 15% and 31%, respectively, of the unwaxed control. Symptom incidence in waxed fruit was not affected by fruit maturity at harvest. Increasing wax:water emulsion concentration up to 50% v/v further decreased symptom incidence and severity with the greater suppression occurring with less than 20% v/v. Crown leaves were extremely susceptible to chilling injury; they turned grey and became desiccated following 8°C storage. Waxing did not affect these symptoms. Waxing assisted in retaining fruit shell appearance and reduced the rate of shell degreening by 60%. The major changes in internal browning and fruit external appearance occurred during holding at room temperature following 8° storage. Varying wax composition with polyethylene and pH had no significant effect on fruit characteristics.**

Internal browning (IB) or endogenous brown spot is the most important physiological disorder of pineapple caused by storage at chilling temperatures (4). The early symptom is the development of a dark spot at the base of fruitlets near the core. The spots coalesce and the tissue finally becomes a dark mass. The history of this malady has been recently reviewed (11).

Internal browning limits both storage (9) and export of pineapple (2). Shipment of fresh pineapples from Hawaii to the U.S. mainland, Japan, and elsewhere has been steadily increasing. In 1980, 101,000 tons were sold as fresh fruit, with 74% being exported from the islands. Only a small proportion of this is shipped by air in unrefrigerated containers, most being sent by sea under refrigeration at 8°C. The normal time from harvest to the U.S. West Coast is 9 days.

Waxing has frequently been used to reduce the symptoms of chilling injury (8). This method has been used on a range of commodities including cucumber, bell peppers, eggplant, tomatoes, and citrus (6). Waxing generally reduces chilling symptoms in grapefruit (3), but greatly increases injury in limes (7). Schappelle (10) studied the physiological effects of waxing pineapples with paraffin on weight loss, sugar and acid content and respiration. However, he did not consider the effect of waxing on the expression of chilling injury or the use of nonparaffin waxes.

Several waxes were tested for their effects on chilling injury in preliminary studies (9). Of these, 2 groups showed significant control, carnuba-paraffin (Decco peach)[5] and paraffin-polyethylene (FMC Stafresh 705)[5]. The following report presents more detailed studies of the effects of these waxes on incidence and severity of IB.

Materials and Methods

'Smooth Cayenne' fruit was hand-harvested on the morning of the experiment from either Castle and Cooke Foods (Dole) Co. or Del Monte Corp. fields on the island of Oahu from June 1980 to March 1981. Fruit was generally at the commercial harvest stage with 0 to 20% yellow shell and weight from 1.5 to 2.0 kg. In 2 tests requiring fruit of different maturities, fruit with up to 60% yellow were used. Treatments were applied within 6 hr after harvest.

Fifteen fruit of comparable surface colors, in 3 replications of 5 fruit each, were selected for each treatment and a harvest date evaluation. The various water wax emulsion treatments, containing 1200 or 2400 ppm benomyl, were applied by total immersion of the fruit in the emulsion-fungicide mix. A water-benomyl treatment served as a control. The surface was allowed to partially dry before packing, 5 fruit per commercial box. Fruit were chilled at 8°C and 90–95% relative humidity (RH) for varying lengths of storage to 4 weeks followed by 1 week at room temperature (22°; 70–85% RH) before final evaluation. This storage sequence simulated sea surface shipment and conditions encountered in retail marketing.

The initial 15 fruit sampled, and the control and treated fruit, were evaluated for the following characteristics after chilling and holding at room temperature: crown appearance on a 1 to 4 scale (good to bad); shell color on a 0 to 5 scale (green to 100% yellow); shell appearance on a 1 to 4 scale (good to bad); incidence of IB and severity of IB on a 0 to 6 scale (none to complete IB). The IB score was done after cutting away the shell and external flesh to expose the central tissue around the core. Also determined was the degree of pulp translucence on a 0 to 4 scale (opaque to translucent).

All experiments were duplicated and results cross checked against response of related treatments in different experiments. CV ranged from 25 to 38%.

Results

Incidence and severity of IB. Preliminary studies showed that 20% v/v wax to water emulsion of FMC-Stafresh 705 (FMC-705) was superior to most waxes in reducing IB (Table 1). The

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[4]The authors express their appreciation for fruit provided by Castle and Cooke Foods (Dole) Co. and Del Monte Corp. and for the technical assistance provided by Theodore Goo and Shirley Lee.

[5]Abbreviations used: FMC—FMC Corp., Citrus Machinery Div., 3075 12th Street, Riverside, CA 92502. Decco—Decco Tiltbelt, Pennwalt Corp., 1713 S. California Ave., Monrovia, CA 91016.

Table 1. Effects of various commercial wax formulations on control of pineapple internal browning (IB) and shell color development[z]

Wax	Dilution rate (wax:water)	IB control (%)	Shell color[x]
FMC Stafresh 705	1:2	100	2.2
FMC Stafresh 705	1:4	100	2.4
Decco peach wax	1:2	100	2.5
Decco peach wax	1:4	85	3.3
Decco 102	1:4	100	3.5
Decco 101	1:4	90	3.0
Decco plum wax	1:2	81	—
Decco 100	1:4	73	3.7
Decco pineapple lustr I	1:4	43	3.0
FMC Stafresh 700	1:4	43 NS[y]	3.4
Decco regular citrus	1:4	39	3.7
Brogdex	1:9	36 NS	4.9 NS
Decco experimental pineapple	1:4	31 NS	4.5
Decco Y-Florida citrus	1:4	23 NS	4.3
Decco pineapple lustr II	1:4	22 NS	4.0

[z]From several tests; hence comparison only with control within test.
[y]Nonsignificant from control ($P \geq 0.05$).
[x]Shell color 0–5 scale (green to 100% yellow) controls scored in range 4 to 5.

waxes all reduced shell color development. Therefore, FMC-705 was utilized in all subsequent tests. Waxing of pineapple fruit with FMC-705 significantly reduced the incidence of I.B. symptoms by 85% (Fig. 1A) and their severity by 69% (FIg. 1B). One week of chilling at 8°C was sufficient to cause symptom development; and the number of fruit affected increased with length of storage period in both waxed and unwaxed fruit (Fig. 1A). The severity of symptoms increased with 2 weeks of chilling for unwaxed but not for waxed fruit (Fig. 1B). IB incidence increased slower in more mature unwaxed fruit than in immature unwaxed fruit (Fig. 1A). Symptom severity did not differ significantly among waxed fruit with 0 to 20%, 40 to 50%, or 60 to 80% shell yellowing.

Wax thickness effect on IB symptoms. Increasing the concentration of FMC-705 wax from 0 to 50% (v/v) in the water-wax mixture resulted in a decrease of symptom incidence (Fig. 2A). Wax concentration above 14% had no additional significant effects on severity (Fig. 2A).

Effect of waxing on fruit appearance. The most significant effects of FMC-705 waxing were on shell appearance and shell color (Fig. 2A, 3 and 4). Shell appearance was retained in waxed fruit during and up to 4 weeks of storage at 8°C, and fruit maturity did not influence this maintenance of appearance (Fig. 3B). Shell appearance deteriorated in unwaxed fruit, but was not significantly affected by holding periods of 3 days or less at room temperature (Fig. 4B). Waxing fruit reduced shell shrivelling and appearances of blemishes, although there was no significant difference in water loss between waxed (7.4%) and unwaxed (6.2%) fruit after 4 weeks of storage at 8° and 1 week at 22°.

Shell color was retained in FMC-705 waxed fruit (Fig. 3A and 4A). Color change from the value at harvest to that obtained after 1 week of storage at 8°C plus 1 week at room temperature was the same as the changes which occurred when the fruit was left for a week at room temperature (Fig. 4A). Increasing periods of storage at 8° had no significant effect on the degreening of waxed fruit, with all of the degreening taking place during the room temperature phase of the test (Fig. 4A). Waxing significantly reduced the rate of degreening during the first 3 days at room temperature (Fig. 4A).

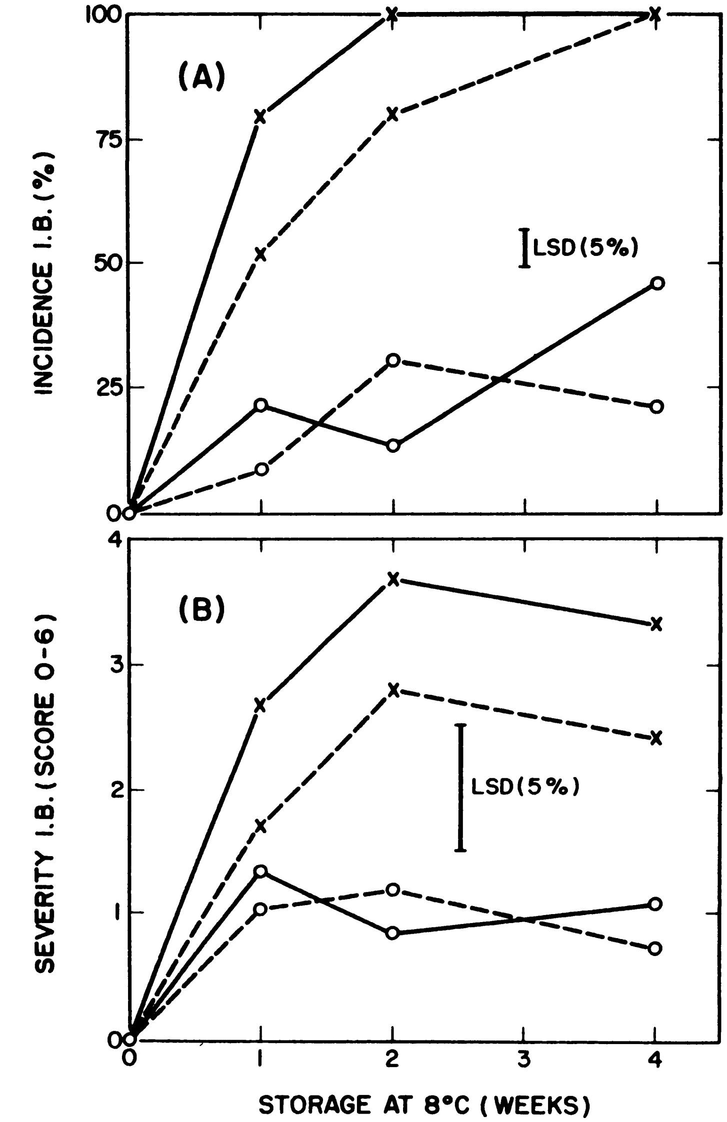

Fig. 1. Effects of length of storage at 8°C on the incidence (A) and severity (B) of internal browning (IB), evaluated 1 week after transfer from 8° to 22°. Wax FMC-704 (1:4) (o); no wax (×), Harvest shell color score of 0–1 indicated by solids lines, score of 3 indicated by dashed lines. Shell color at harvest was scored on a scale of 0–5 corresponding with the fruit shell color range of green to full yellow.

Loss of crown appearance, due to bleaching and wilting of leaves, increased with storage time at 8°C when evaluated after 1 week at room temperature (Fig. 3C). Waxing did not affect the rate of damage development (Fig. 4C). Crown damage became apparent during the 22° storage subsequent to 8° storage (Fig. 4C). There was, however, a significant difference between waxed and unwaxed fruit at 2 weeks of storage at 8° and with different maturities (Fig. 3C), although the difference did not occur with 1 and 4 weeks of storage and consistently in other experiments.

Wax characteristics and fruit appearance. Application of wax concentrations up to 50% (v/v) did not significantly affect crown appearance (Fig. 2B). Varying the content of polyethylene in the wax (addition of FMC-700) or varying the pH of the wax from 12 to 4 with citric acid did not influence final crown appearance either (data not shown).

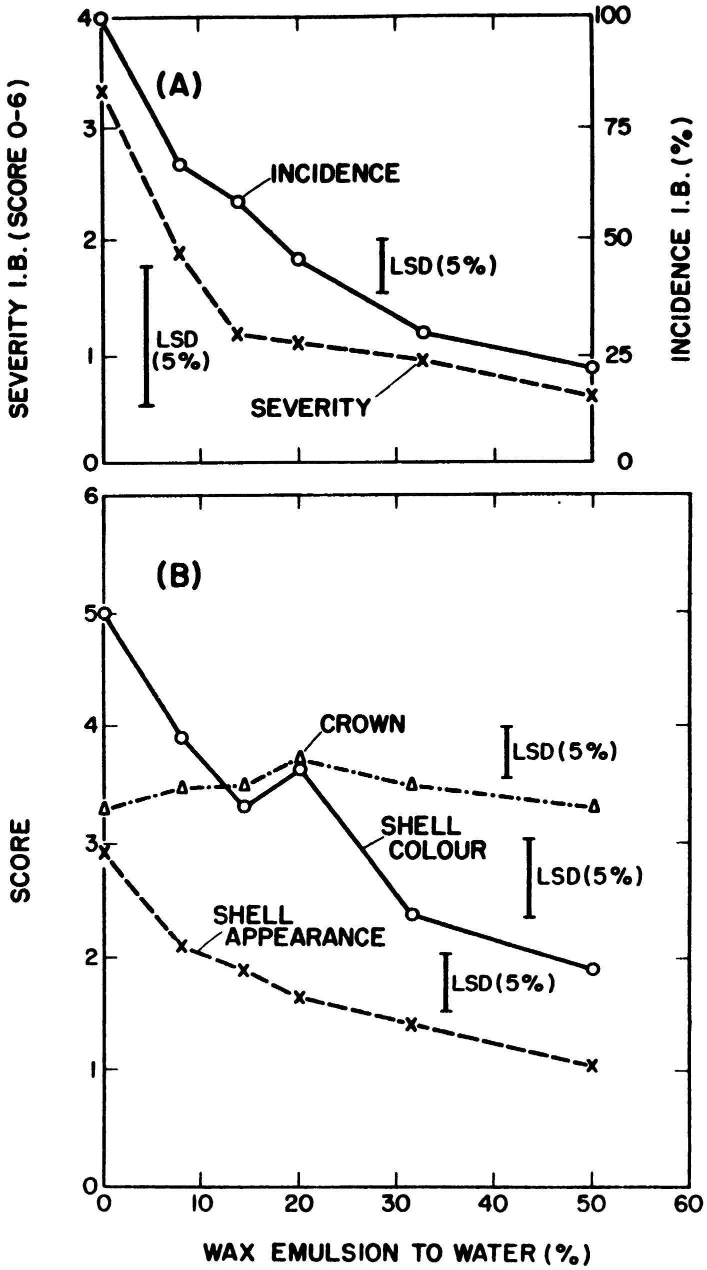

Fig. 2. Influences of varying wax-water emulsion concentrations on (A) incidence (o) severity (×) of internal browning, and on (B) shell color (o), shell appearance (×), and crown condition (△). Fruit were evaluated after 3 weeks of storage at 8°C followed by 1 week at 22°.

Increasing wax percentage up to 50% (v/v) prevented loss of shell appearance and reduced the rate of degreening (Fig. 2B). Degreening of fruit dipped in 8% wax was significantly reduced following 3 weeks of 8°C storage and 1 week at room temperature, and shell appearance was retained.

Varying the pH or the percentage of polyethylene up to 100% polyethylene (FMC-700) in the standard wax (FMC-705) had no apparent effect on incidence or severity of IB, crown appearance, shell color, or appearance.

Waxing and fruit translucence. Translucence increased with increased storage time at 8°C (Table 2). Waxing did not influence the increase in translucence in less mature fruit, but did in more mature fruit with longer storage at 8°. Varying the pH, per-

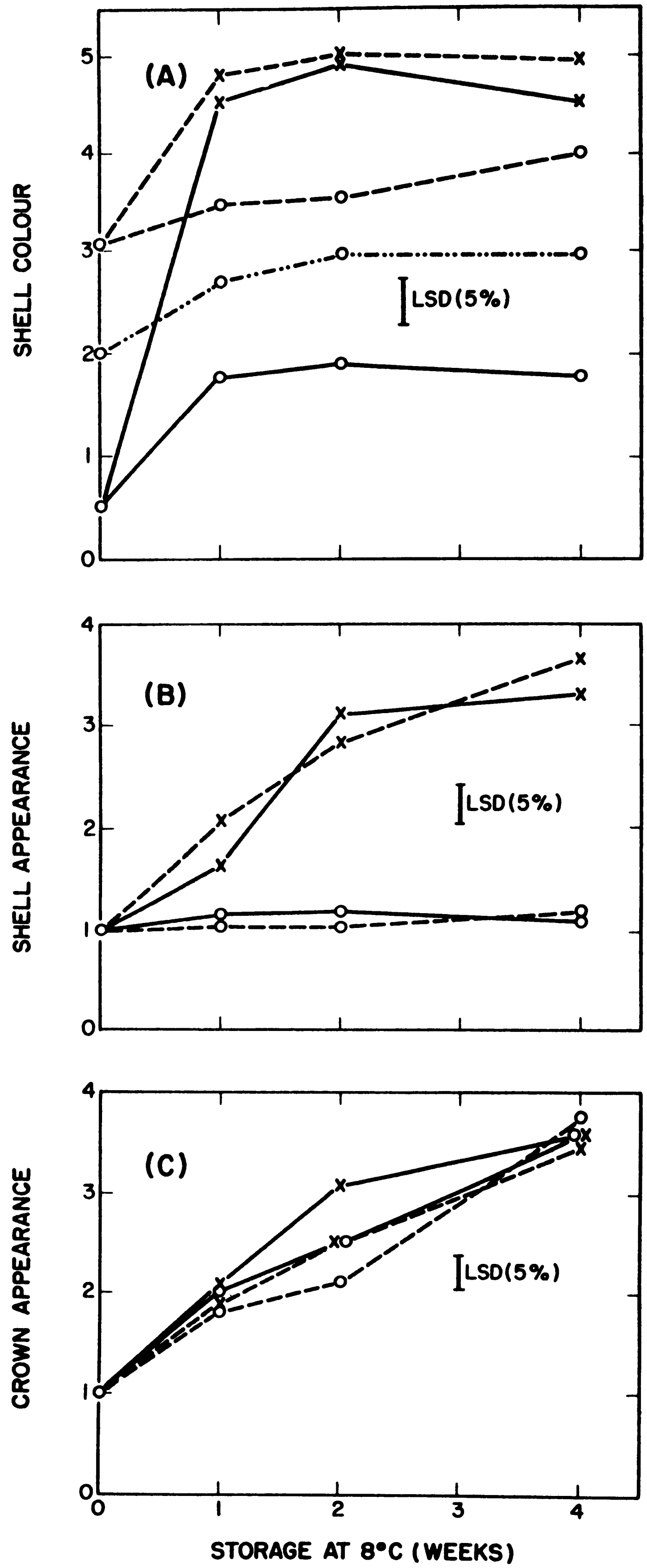

Fig. 3. Effects of length of storage at 8°C on (A) shell color, (B) shell appearance, and (C) crown appearance. Fruit were evaluated 1 week after transfer from 8° to 22°. Fruit were waxed with 20% (v/v) wax-water emulsion of FMC-705; (o) waxed, (×) no wax. Harvest shell color score of 0–1 indicated by solids lines; score of 3 indicated by dashed lines.

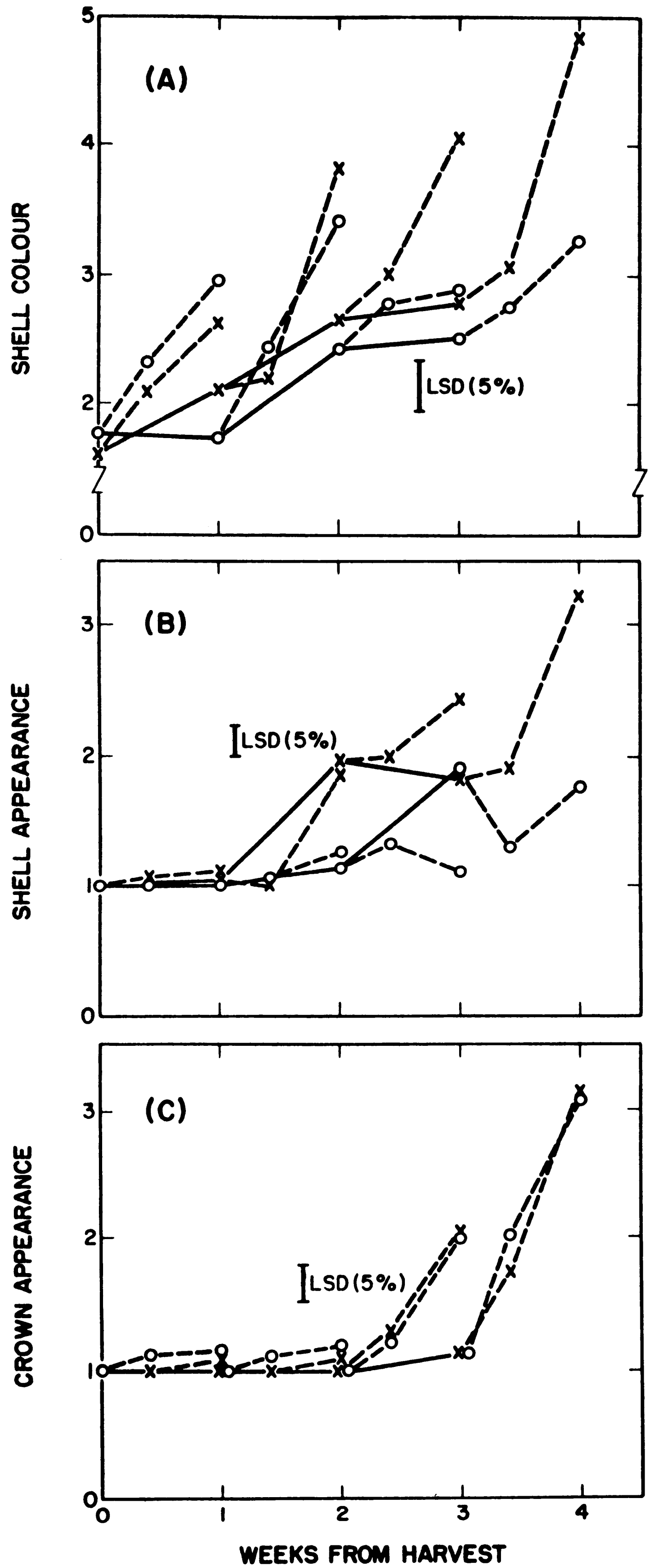

Fig. 4. Effects of different lengths of storage at 8°C followed by 1 week at room temperature (22°) on changes in (A) shell color, (B) shell appearance, and (C) crown appearance. Fruit waxed with a 20% (v/v) wax-water emulsion of FMC-705: (o) waxed, (×) no wax. Evaluation after 8° indicated by solid lines, and after 22° indicated by dashed line.

Table 2. Effect of time of storage at 8°C and waxing with 20% v/v water wax emulsion (FMC-705) on fruit translucence

Treatment (weeks at 8°C)	Fruit translucence rating[z]			
	Shell color score of 0.5		Shell color score of 3.1	
	No wax	Wax	No wax	Wax
0	1.7 hi[x]	1.7 hi	1.4 i	1.4 i
1	1.7 hi	1.9 hi	2.1 gh	2.9 de
2	2.7 def	2.1 gh	2.1 gh	3.3 bcd
4	3.3 bcd	3.5 abc	2.6 efg	3.6 ab

[z]0 = opaque; 4 = translucent
[y]Shell color score at harvest on a 0 (green) to 5 (100% yellow) scale.
[x]Mean separation by Duncan's multiple ranges test, 5% level.

centage polyethylene in wax or wax concentration had no significant effect on translucence.

Discussion

Waxing pineapples reduced the severity and incidence of chilling injury, affording extra storage time. However, it did not prevent chilling injury. After a week at 8°C and a week at room temperature, 20% of the waxed fruit had some IB, similar to the symptoms described as endogenous brown spot (2), while 75% of the unwaxed fruit had severe internal browning (Fig. 1A and 1B). It was unclear whether waxing reduced injury *per se* or symptom expression. Waxing apparently was not protecting the fruit by preventing water loss (8), as water loss was similar for both waxed and unwaxed fruit.

A major appearance problem with fruit stored at 8°C was the severe crown damage which occurred (1). The crown was more prone to chilling injury than the fruit itself and this was a more visible symptom of damage. Crown damage increased progressively with longer storage, with little apparent influence of waxing on the degree or incidence or damage (Fig. 4C).

Shell degreening in pineapples is due to loss of chlorophyll rather than a change in carotenoids (5), and was significantly reduced by waxing (Fig. 4A). Schappelle (10) also found that paraffin waxes reduce the rate of degreening in 'Red Spanish'. Increased applications of wax significantly slowed degreening. Since only a thin film of wax significantly affected the rate of degreening, a sensitive mechanism apparently was involved. Internal changes in organic acids, pH and sugars during this period of shell chlorophyll loss were minimal (5), hence palatability was unaffected by waxed-reduced degreening.

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Quantum Flux Density Studies of Chrysanthemum in a Controlled Environment with High-pressure Sodium Lamps. I. Rooting Studies[1]

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Additional index words. photosynthetic active radiation, high-intensity discharge lamps, temperature, photochlorosis, crop production, *Chrysanthemum morifolium*

Abstract. **Growth of chrysanthemum (*Chrysanthemum morifolium* Ramat) was studied as a function of quantum flux density (QFD), QFD duration, and temperature. Unrooted cuttings were rooted under high-pressure sodium (HPS) lamps in a controlled environment (CE) at 4 QFD, 3 QFD durations, and 3 temperatures, and plants were grown to flowering in a greenhouse to determine treatment effect on flowering time and plant size at flowering. Increasing QFD duration was more effective in increasing root and shoot dry weight than increasing QFD. Root and shoot dry weights were greatest at 21°C after 13 days rooting. Light treatment during rooting had no effect on flowering time or shoot length at flowering, but there were differences of up to 35% in fresh weight at flowering. A photochlorosis was observed on all treatments irradiated with HPS lamps; the photochlorosis was irreparable at a QFD of 420 $\mu Em^{-2}s^{-1}$.**

Irradiance, daylength, temperature, and CO_2 environment effects on chrysanthemum growth and development under fluorescent lamps in controlled environments (CE) has been reported (6, 7, 9, 10, 11, 12, 13, 14). Increasing the irradiance proportionally increased plant dry weight; the importance of total irradiation on flower initiation during the first 3 weeks of short days (SD) has been well-described. The rate of development was the same for plants grown at a constant irradiance and at a varying irradiance during the day, as long as total daily irradiation was equal (6, 12). Further study (7) indicated that chrysanthemums could integrate total irradiation from 2 consecutive days if the irradiances were less than the light saturation level. However, Hughes' reciprocity studies (9, 10) showed that plants grown at lower irradiances and longer SD (12 hr) for the entire SD period had significantly greater dry weight and leaf area, but flowered 6 days later than the higher irradiance 8 hour SD treatment, even though total daily irradiation was equal. Increasing the daylength 50% resulted in greater dry weight increases than 50% increases in irradiance. Considerable variation among replications was reported in some studies (11, 13) indicating the difficulty and importance of selecting uniform plant material when studying chrysanthemums.

High-intensity discharge (HID) lighting is becoming a widely used tool in CE research and in commercial greenhouse production (1, 8, 16, 18). Several researchers (3, 4, 5, 15) have reported the benefits of supplemental HID lighting of chrysanthemums during rooting, long days (LD), and SD, including increased plant weight, improved quality, and earlier flowering. It appears the greatest benefits from HID lighting, horticulturally and financially, can be realized when plants are irradiated during the early stages of growth.

Buck (2) reported excellent quality and control of lettuce seed germination when seed was germinated in a CE with HID lighting. It seemed a similar system could be developed for chrysanthemum production so cutting costs and greenhouse production time could be reduced and quality, yields, and return on investment could be increased. Studies were made to determine the effect of quantum flux density (QFD), QFD duration, and temperature on chrysanthemum growth during rooting when grown in a CE under high-pressure sodium (HPS) lamps. The effect of the treatment on flowering time, fresh weight, and stem length was also determined.

Materials and Methods

The rooting stage (days 1–13) was artifically defined. Studies were conducted in a glass greenhouse with black cloth suspended from eave to eave and around the perimeter; natural QFD measured during the day was less than 0.2 $\mu Em^{-2}s^{-1}$. Irradiation was provided by two 400W Lucolux HPS lamps in General

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