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# POSTHARVEST FACTORS INFLUENCING STEM-END RIND BREAKDOWN (SERB) OF 'VALENCIA' ORANGES

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*Abstract.* **Severe stem-end rind breakdown (SERB) of 'Valencia' oranges [*Citrus sinensis* (L.) Osb.] exported from Florida to Korea and Taiwan has been reported in recent years. The effects of clipping vs. pulling, coating application, storage temperature, and fruit size on SERB of 'Valencia' oranges were studied during the 1998-1999 and 1999-2000 seasons. These studies demonstrated that storage temperature is the most significant factor influencing SERB of 'Valencia' oranges. Three weeks after packing, fruit stored at 70°F (21°C) with 70 ± 3% relative humidity (RH) had 61% SERB, while fruit stored at 40°F (4°C) under the same RH had only 1.3% SERB. Coating application and formulation did not result in consistent effects on fruit SERB incidence. Fruit size and harvesting methods (pulling vs. clipping) did not significantly influence the incidence of fruit with SERB symptoms.**

Stem-end rind breakdown (SERB) is a severe postharvest peel disorder of oranges. The disorder involves collapse and subsequent darkening of the epidermal tissues around the stem end of fruit. SERB is characterized by a narrow ring of undamaged tissue immediately around the calyx (Grierson, 1986), and often extends several centimeters from the fruit button (Fig. 1). Albrigo (1972) found that this limited area had no stomata and was characterized by a thick layer of cuticular wax. Scanning electron-microscopy shows that epidermal cells, subepidermal cells, and surrounding cells are collapsed in fruit with SERB symptom (Fig. 1). In contrast, postharvest pitting, another peel disorder, often targets the oil gland (Petracek and Dou, 1998).

Hopkins and McCornack (1960) demonstrated that SERB development in susceptible fruit is related to humidity during degreening. 'Valencia' oranges can develop SERB after 2 or more days exposure to environments with low relative humidity (RH) and high rates of air flow around the commodity. Under such conditions, SERB appears about 6-7 d after picking (McCornack and Grierson, 1965). The drying conditions between the grove and the degreening room can play an important role in SERB development (Grierson, 1965). McCornack and Grierson (1965) suggested that keeping fruit shaded and avoiding direct fruit exposure to the sun and drying winds reduce SERB. In general, prompt handling of oranges after harvesting and maintaining high relative humidity before and after packing are important steps to minimize SERB development (Hopkins and McCornack, 1960; Grierson, 1965, 1986).

Grierson (1965) summarized the results of many years of research on preharvest factors affecting SERB development conducted at the Citrus Research and Education Center in Lake Alfred, Florida. Generally speaking, preharvest factors such as moisture conditions or applied irrigation, N, and K did not significantly influence the incidence of fruit with SERB. This suggests that other factors are involved in the occurrence of SERB (Grierson, 1965).

In recent years, severe SERB of 'Valencia' and 'Hamlin' oranges exported from Florida to southeast Asian countries such as Korea has been reported. The incidence of SERB is often high because optimum postharvest handling practices are not maintained. Furthermore, harvesting and postharvest handling practices and coating formulations have changed within the past decade and their effects on SERB is not known. The objective of this research was to investigate how fruit sizes, new commercial coating formulations, storage temperatures, and harvesting methods (clipping vs. pulling) influence the incidence of SERB of 'Valencia' oranges.

## Materials and Methods

*Study 1. Effect of coating formulations, fruit size, and clipping/pulling on SERB of 'Valencia' oranges (1999).*

'Valencia' oranges [*Citrus sinensis (L.) osb.*] on Carrizo citrange [*Citrus sinensis* (L.) Osb. × *Poncirus trifoliata* (L.) Raf.] rootstock were clipped or pulled on 21 May 1999 from a grove in Polk County, Fla. Fruit were washed (SOPP, Freshgard 5, FMC Corporation, Lakeland, Fla.) and sized immediately after harvesting using a Color Vision Systems (Victoria, Australia). Size 100 and 64 fruit were coated with commercial shellac or carnauba wax (FMC Corporation, Lakeland, Fla.; EcoScience, Orlando, Fla.), respectively. After coating application, fruit were dried at approximately 131°F (55°C) for 2 min and packed into 4/5-bushel fiberboard cartons (approximately 40 kg). No fungicide was applied in this and the following studies. Fruit were stored at 70°F (21°C) with 70 ± 3% RH and evaluated for SERB development after 16 and 32 d in storage. The study consisted of a factorial design with two harvesting methods, two fruit sizes, and two types of coating. Each treatment was replicated three times with 60 fruit per replicate.

*Study 2. Effect of coating formulations, storage temperature, and clipping/pulling on SERB of 'Valencia' oranges (1999).*

'Valencia' oranges on Carrizo citrange rootstock were clipped or pulled on 25 May 1999 from a grove in Polk County, Fla. Fruit were washed with SOPP and coated immediately

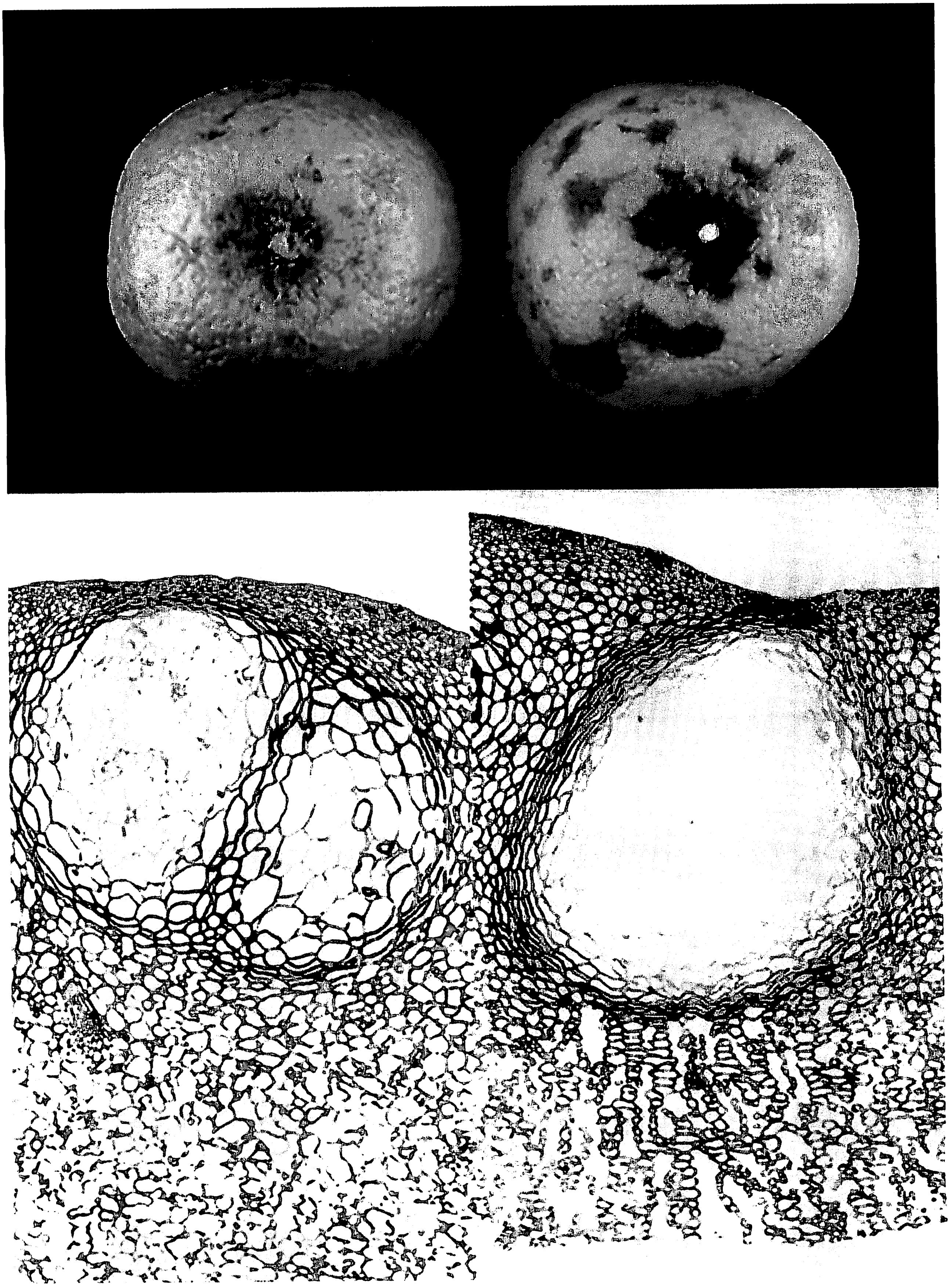

Figure 1. SERB symptom incidence of 'Valencia' oranges (top). Scanning electron microscopy with healthy tissue (lower left) and collapsed peel of SERB (lower right). The lower right picture shows that epidermal cells, subepidermal cells and enveloping cells are collapsed in fruit with SERB symptoms, whereas postharvest pitting often targets the oil gland and enveloping cells.

upon arrival with commercial shellac or carnauba wax as described above. A non-coated treatment was also included in this study as a control. After coating application, fruit were dried at approximately 131°F (55°C) for 2 min and packed into 4/5-bushel fiberboard cartons (40 kg). Fruit were stored at 70°F (21°C) with 70 ± 3% RH or 40°F (4°C) with 70 ± 3% RH and evaluated for SERB development after 18 d. The study consisted of a factorial design with two harvesting methods, three types of coating and two storage temperatures. Each treatment was replicated three times with 60 fruit per replicate.

*Study 3. Effect of coating formulations, fruit sizes, and storage temperatures on SERB of 'Valencia' oranges (2000).*

'Valencia' oranges (unknown rootstock) were commercially harvested on 25 Apr. 2000 from a grove in Polk County, Fla. and delivered to a commercial packinghouse in the same county where they were held overnight under ambient conditions. The next morning, fruit were transported to the Citrus Research and Education Center in Lake Alfred, Fla. where they were washed with SOPP as above and graded using a Color Vision Systems. The day/night temperature at this period varied from 64 (night) to 84 (day) °F, and minimum RH was 36% in the packinghouse. Large (> size 64) and small (< size 125) oranges were randomly selected and coated with commercial shellac or a carnauba wax (FMC, Lakeland, Fla., and Pace International, Seattle, Wash., respectively). A non-coated treatment was included in this study as a control. After coating application, fruit were dried at approximately 131°F (55°C) for 2 min and packed into 4/5-bushel fiberboard cartons (40 kg). Fruit were stored at 38°F (3°C) with 70 ± 3% RH or at 70°F (21°C) with 70 ± 3% RH for 2 months. Each treatment was replicated three times with 60 fruit per replicate.

*Study 4. Effect of coating formulations on SERB and storage quality of 'Valencia' oranges (2000).*

'Valencia' oranges were commercially harvested on 25 Apr. 2000 and received at the Citrus Research and Education Center on 26 Apr. 2000 (night/day temperature: 64- 84°F, RH: 36%) from a packinghouse in Polk County, Fla. The cultivar and rootstock of fruit used were unknown. After fruit were washed and sized, medium sized fruit (between 64 and 100) were randomly coated with one of the eight different coating formulations. These included one carnauba and one shellac coating from each of three companies: FMC (Lakeland, Fla.), Decco (Monrovia, Calif.), and Pace International (Seattle, Wash.). The two polyethylene coatings came from FMC (Lakeland, Fla.) and Decco (Monrovia, Calif.). A non-coated treatment was included as a control. After coating application, fruit were dried at approximately 131°F (55°C) for 2 min and packed into 4/5-bushel fiberboard cartons (40 kg). Fruit were stored at 38°F (3°C) with 70 ± 3% RH for 142 d before being evaluated for SERB development. This study was a completely randomized design. Each treatment was replicated three times with 60 fruit per replicate.

*Fruit evaluation*

SERB symptoms occur almost exclusively near the stem end of fruit and typically encircle the stem end (Grierson, 1986). In this study, SERB was visually rated as present or absent if symptoms clearly appeared (refer to each study for exact fruit examination data).

*Internal gas level*

Ten fruit from each treatment were randomly selected for gas analysis in Study 4. On the stylar end of the fruit, septa were created by applying about 0.5 cm diameter dabs of DOW 3140 RTV silicone (Midland, Mich.). Gas samples of 0.2 ml were taken from the internal air space of the fruit by syringe for $O_2/CO_2$ analysis. Internal $O_2$ and $CO_2$ concentrations of fruit were measured by a flow-through system consisting of $O_2$ (Model 26112, Orbisphere Laboratories, Geneva, Switzerland) and $CO_2$ (Model LI-6251, Li-Cor, Lincoln, Neb.) gas analyzers connected in series with $N_2$ used as the carrier gas.

*Fruit shine*

Fruit shine (gloss) was measured 18 and 60 d after coating application in Study 4 using a Model Micro-Tri-gloss meter (BYK Gardner, Silver Springs, Md.). Ten fruit from each treatment were randomly selected. High values represent greater fruit shine (higher gloss) compared to low values that represent less shine.

*Weight loss*

Fruit weight loss was determined by weighing the 10 fruit 0, 7, and 14 d after coating application and was expressed as percent weight lost per day.

*Color*

Fruit color was measured on ten fruit using a Minolta-Colorimeter (Minolta, CR-300, Japan) and expressed as hue angle (h°) and chroma (C*). The hue angle is a measure of color that from 0° to 90° spans from red to yellow. An orange color has a hue angle of approximately 75°. Chroma is a measure of color intensity with low values representing dull colors and high values representing vibrant colors.

*Statistics*

Experimental data were statistically analyzed using Plotit (Scientific Programming Enterprises, Haslett, Mich.). All data from Studies 1-3 were analyzed using factorial analysis of variance. The data from Study 4 was analyzed as a completely randomized design and analysis of variance was used. Means were separated using Duncan's multiple range test at $P \leq 0.05$.

## Results

In the first study, the percentage of 'Valencia' oranges with SERB symptoms varied among the eight treatments from 2.5 to 12.4% at day 16, and 13.6 to 35.7% at day 32 (data not shown). The incidence of SERB increased as length of storage at 70°F (21°C) with 70 ± 3% RH increased from 16 to 32 d. There were no significant differences in SERB development among most treatments 16 d after packing (data not shown). At day 32, a significantly lower percentage of fruit with SERB was found in carnauba-coated fruit (Table 1). In the second study, 61.2% of the fruit developed SERB after 18 d of storage at 70°F (21°C) with 70 ± 3% RH. However, only 1.3% of the fruit developed SERB if stored at 40°F (4°C) with 70 ± 3% RH (Table 2). Similar results were found in the third study that was conducted in the summer of 2000 (Fig. 2). Eighteen percent of the fruit developed clear SERB symptoms when stored at 70°F (21°C), while only 7% SERB incidence was found on

Table 1. Effects of harvesting methods, coatings, and fruit size on SERB incidence (%) of 'Valencia' oranges.[z]

| | Summary of factorial analysis |
|---|---|
| Clip/pull (A) | NS[y] |
| Fruit size (B) | NS |
| Coating formulation (C) | * |
| A × B | NS |
| A × C | NS |
| B × C | NS |
| A × B × C | NS |
| | Table of means |
| Coating type | |
| Shellac | 30.5 |
| Carnauba | 20.3 |

[z]Fruit were harvested and treated on 21 May 1999 and stored at 70°F (21°C) with 70% RH for 32 d. Only the significant data among treatments are presented.
[y]NS = Non-significant, * significantly different, $P \leq 0.05$.

Table 2. Effects of harvesting methods, coatings, and storage temperature on SERB and weight loss of 'Valencia' oranges[z].

| | SERB | Weight loss |
|---|---|---|
| | Summary of factorial analysis | |
| Clip/pull (A) | NS[y] | NS |
| Storage temperature (B) | *** | *** |
| Coating formulation (C) | *** | ** |
| A × B | NS | NS |
| A × C | ** | NS |
| B × C | ** | NS |
| A × B × C | ** | NS |
| | % of fruit with SERB | Wt loss (%/day) |
| Coating type | | |
| No coating | 23.8 | 0.292 |
| Shellac | 29.1 | 0.243 |
| Carnauba | 40.9 | 0.148 |
| Storage temperature | | |
| 40°F | 1.3 | 0.126 |
| 70°F | 61.2 | 0.329 |
| Interactions | | |
| Harvesting methods × coatings | | |
| Clip × non-coated | 20.8 | |
| Pull × non-coated | 26.7 | |
| Clip × shellac | 25.0 | |
| Pull × shellac | 33.3 | |
| Clip × carnauba | 48.1 | |
| Pull × carnauba | 33.7 | |
| Temperature × coatings | | |
| 70°F × non-coated | 47.5 | |
| 70°F × shellac | 57.8 | |
| 70°F × carnauba | 78.3 | |
| 40°F × non-coated | 0.0 | |
| 40°F × shellac | 0.5 | |
| 40°F × carnauba | 3.5 | |
| Clip/pull × temperature × coating type | | |
| Clip × 70°F × non-coated | 41.5 | |
| Pull × 70°F × non-coated | 53.4 | |
| Clip × 70°F × shellac | 49.0 | |
| Pull × 70°F × shellac | 66.5 | |
| Clip × 70°F × carnauba | 92.2 | |
| Pull × 70°F × carnauba | 64.5 | |
| Clip × 70°F × non-coated | 0.0 | |
| Pull × 70°F × non-coated | 0.0 | |
| Clip × 70°F × shellac | 1.1 | |
| Pull × 70°F × shellac | 0.0 | |
| Clip × 70°F × carnauba | 4.0 | |
| P × 40°F × carnauba | 2.9 | |

[z]Fruit were harvested on 25 May 1999 and evaluated on 11 June 1999 for SERB. Only the significant data among treatments are presented.
[y]NS = Non-significant; **, *** significantly different at $P \leq 0.01$, and 0.001, respectively.

fruit stored at 40°F (4°C). In the second and third study, there was no significant difference in SERB incidence between fruit coated with shellac coating and those coated with carnauba wax (Table 2, Fig. 2). Fruit size and harvesting methods (pulling vs. clipping) did not significantly influence the development of fruit SERB (Tables 1 and 2, Fig. 2). Fruit weight loss in the second study was higher at 70°F (21°C) with 70 ± 3% RH compared with 40°F(4°C) with 70 ± 3% RH (Table 2). Factorial analysis indicated a lower weight loss in fruit coated with carnauba wax than with shellac.

The coating formulation study during long-term cold storage (Study 4) showed no clear difference in percentage of fruit with SERB symptoms among nine treatments (Table 3). Even though some individual values were significantly different from each other (shellac coating 2 and polyethylene coating 2 resulted in the highest and lowest SERB, respectively), there were no obvious differences between the shellac, carnauba, or polyethylene coating groups (Table 3). Similar to fruit with SERB incidence, there was no clear difference regarding fruit decay incidence among coating treatments. Carnauba wax 3 resulted in the lowest decay among nine treatments, which was significantly lower than four other treatments. All eight coatings reduced fruit weight loss compared to non-coated fruit, but no trend was found among the three coating groups (shellac, carnauba, and polyethylene). Coating application tended to reduce fruit internal $O_2$ and increase internal $CO_2$ concentrations. Shellac significantly increased fruit shine in comparison to either non-coated fruit or fruit coated with polyethylene or carnauba, evaluated 16 d or 70 d after packing (Table 4). Shine tended to decrease between day 16 and day 70 on fruit coated with carnauba wax and stored at 38°F (3°C). Not all carnauba and polyethylene coatings increased fruit shine compared to non-coated fruit. Hue angle of 'Valencia' oranges was not significantly influenced by application of any of the coatings. However, chroma was significantly lower in shellac-coated fruit than that in non-coated fruit (Table 4).

## Discussion

Storage temperature is a key factor influencing the development of SERB. At high temperatures, fruit respire and lose water faster than at low temperatures. So it is not surprising that SERB was much more severe at 70°F (21°C) than at 40°F (4°C) (Table 2, Fig. 2). Brown and Miller (1999) and Dou and Ismail (2000) indicated that the optimal storage temperature for oranges and tangerines is between 33-40°F (0.5-4°C). Peeples et al. (1999) used 33°F (0.5°C) for the long-term storage of 'Valencia' oranges. It is well known that temperature affects respiration rate by influencing enzyme activity (Mengel, 1994) and that respiration increases two to four fold for every 10°C rise in temperature (Thompson et al., 1998).

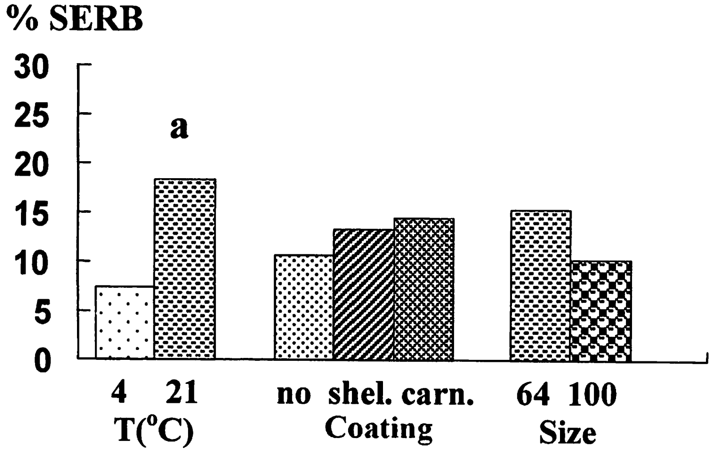


Figure 2. Effect of coatings, storage temperature, and fruit size on SERB of 'Valencia' oranges. Fruit were harvested on 25 Apr. 2000 and evaluated on 5 Jun. 2000. Factorial analysis indicated a significant difference between the storage temperatures ($P \leq 0.05$). No statistical differences were found among coating formulations or fruit sizes.

Non-coated fruit resulted in the highest fruit weight loss among the coating treatments (Tables 2 and 3). Coating application reduces fruit weight loss, decreases fruit internal $O_2$ concentrations, and increases internal $CO_2$ concentrations (Table 3; Dou et al., 1999; Hagenmaier and Shaw, 1992; Hall, 1981; Petracek et al., 1998). Fruit may exhibit deformation if fruit weight loss reaches approximately 5-7% (Hagenmaier, 1998). The carnauba waxes used in these studies came from three different vendors, which may explain why carnauba did not always show a consistent effect on fruit SERB incidence, weight loss, and color development (Tables 1, 2, and 3). In general, carnauba wax formulations have undergone the greatest change over the past few years. This is likely because fruit coating manufacturers have been working to increase the shine of carnauba wax so that it is comparable to that of shellac coatings (Dou et al., 1999).

In the present study, shellac coatings tended to increase fruit shine more than carnauba wax (Table 4). This is consistent with the reports of Dou et al. (1999), Petracek et al. (1998), and Hagenmaier (1998). Low chroma suggests that the shellac prevented the dulling of fruit color. However, shellac tended to result in higher decay compared to carnauba and polyethylene, although this was not statistically significant (Table 3). Shellac may also cause physiological breakdown in citrus during long-term storage (Brown et al., 1998). Considering all postharvest parameters such as SERB, decay, fruit gas exchange, weight loss, and color measured in this paper (Tables 3 and 4), polyethylene coating is the best choice for long term storage of 'Valencia' oranges.

Researchers have suggested that SERB is more severe in small, thin-skinned fruit (Grierson, 1965, 1986). Our experiments did not find any significant differences in SERB development between small and large fruit (Table. 1). Due to changes in postharvest handling practices in the last 20 years, the effect of clipping vs. pulling on SERB incidence of 'Valencia' oranges was evaluated in these studies. However, neither clipping or pulling significantly influenced the fruit SERB development (Tables 1 and 2). Hopkins and McCornack (1960) reported that clipping or pulling in non-coated fruit did not significantly affect SERB development.

Grierson (1986) also suggested that SERB might be initiated by a preharvest nutrition-imbalance but was unable to find significant differences in the nutrition studies he summarized. Recent nutrition and irrigation studies on 'Fallglo' tangerines and 'Valencia' oranges have not shown any significant effect of irrigation, N, and K levels on fruit SERB development (H. Dou; unpublished data).

In the current study, fruit were treated within 24 h of harvest and immediately stored at 70 or 40°F. This fast handling process might enhance the effect of storage temperature on SERB incidence more than any other factor such as delayed packing. The results of this study demonstrated that storage temperature is a key factor in the development of SERB of 'Valencia' oranges. Optimal storage temperature in combination with proper postharvest handling is required to maintain high quality fruit and reduce SERB development in 'Valencia' oranges.

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Table 3. Effect of different coating formulations on SERB development, decay, water loss, internal $O_2$ concentration, and internal $CO_2$ concentration of 'Valencia' oranges after 5 months storage at 38°F[z].

| | SERB (%) | Decay (%) | Wt. loss (%/day) | Oxygen (%) | $CO_2$ (%) |
|---|---|---|---|---|---|
| No coating | 21.88 ab | 15.49 abc | 0.063 e | 20.41 d | 1.20 a |
| Carnauba 1 | 31.27 abc | 9.23 ab | 0.039 c | 17.69 abcd | 1.06 a |
| Carnauba 2 | 21.35 ab | 21.27 bc | 0.033 ab | 16.45 abc | 2.30 a |
| Carnauba 3 | 34.22 bc | 4.15 a | 0.034 ab | 17.39 abcd | 2.61 ab |
| Polyethylene 1 | 34.05 bc | 15.77 abc | 0.039 c | 19.11 cd | 2.27 a |
| Polyethylene 2 | 12.72 a | 21.85 bc | 0.036 bc | 14.79 a | 0.85 a |
| Shellac 1 | 31.31 abc | 28.49 c | 0.045 d | 18.03 bcd | 2.30 a |
| Shellac 2 | 43.66 c | 23.91 bc | 0.035 abc | 14.86 ab | 4.91 c |
| Shellac 3 | 20.86 ab | 18.30 abc | 0.030 a | 18.09 cd | 2.21 a |

[z]Fruit were harvested and coated on 25 Apr. 2000 and evaluated on 21 Sept. 2000. Values within each column followed by unlike letters are significantly different by Duncan's multiple range test, $P \leq 0.05$.

Table 4. Effect of various coatings on fruit shine and color of 'Valencia' oranges stored at 38°F.[z]

| | Time in storage (d) | |
|---|---|---|
| | 18 | 70 |
| | Shine (gloss unit) | |
| No coating | 3.03 a | 3.58 abc |
| Carnauba 1 | 3.84 bc | 3.3 a |
| Carnauba 2 | 3.41 ab | 3.28 a |
| Carnauba 3 | 3.91 c | 3.48 ab |
| Polyethylene 1 | 3.26 a | 3.8 bc |
| Polyethylene 2 | 4.07 c | 3.88 c |
| Shellac 1 | 5.24 d | 5.02 de |
| Shellac 2 | 5.49 d | 5.71f |
| Shellac 3 | 5.05 d | 4.99 d |
| | Chroma[y] | |
| No coating | 72.69 d | 70.99 d |
| Carnauba 1 | 71.67 cd | 70.79 d |
| Carnauba 2 | 69.93 bcd | 69.46 bcd |
| Carnauba 3 | 68.94 abc | 69.26 bcd |
| Polyethylene 1 | 71.87 cd | 70.6 cd |
| Polyethylene 2 | 68.95 abc | 69.15 bcd |
| Shellac 1 | 67.81 ab | 66.89 b |
| Shellac 2 | 67.24 ab | 67.45 bc |
| Shellac 3 | 66.49 a | 62.14 a |
| | Hue angle (°)[x] | |
| No coating | 78.15 a | 78.94 bc |
| Carnauba 1 | 76.46 a | 75.10 a |
| Carnauba 2 | 66.83 a | 76.95 abc |
| Carnauba 3 | 79.17 a | 77.36 abc |
| Polyethylene 1 | 78.24 a | 76.53 ab |
| Polyethylene 2 | 67.45 a | 77.10 abc |
| Shellac 1 | 68.50 a | 77.59 bc |
| Shellac 2 | 74.85 a | 75.01 a |
| Shellac 3 | 76.94 a | 79.23 c |

[z]Fruit were harvested and coated on 25 Apr. 2000. Values within each column at respective shine and color characteristics followed by unlike letters are significantly different by Duncan's multiple range test, $P \leq 0.05$.
[y]Degree of departure from gray toward pure chromatic color.
[x]0° = red-purple, 90° = yellow, 180° = bluish-green, 270° =blue.

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