The Degreening of 'Fallglo' Tangerine

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ABSTRACT. 'Fallglo' (Bower citrus hybrid [*Citrus reticulata* Blanco x (*C. reticulata* Blanco x *C. paradisi* Macf.)] x 'Temple' [*C. reticulata* Blanco x *C. sinensis* L.] is an early season tangerine that is reportedly hypersensitive to ethylene exposure during degreening. The effects of ethylene exposure time, waxing, and storage temperature on 'Fallglo' color were examined to assess degreening strategies. Exposure to 5 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene for 24 or 48 hours hastened degreening, and internal ethylene levels increased following the time periods of ethylene exposure. Fruit not exposed to ethylene, or exposed for shorter periods (2 or 6 hours), degreened slowly during storage at 15.5 °C and internal ethylene levels remained low. Low-temperature storage (4.5 °C) or waxing hindered degreening after ethylene exposure but decreased water loss. Degreening after ethylene exposure was faster for fruit stored at 15.5 than 26.5 °C.

Green, but otherwise mature, citrus fruit are routinely degreened by a process in which the fruit are exposed to ethylene before packing. Ethylene stimulates chlorophyll degradation and, in oranges and tangerines, triggers carotenoid synthesis (Grierson et al., 1986; Stewart and Wheaton, 1972). Although degreening is considered to be essential to producing marketable early season citrus, ethylene exposure stimulates the development of pathogens such as *Colletotrichum gleosporioides* (Penz.) Sacc. (Brown, 1992; Smoot and Melvin, 1967) and *Diplodia natalensis* (Barmore and Brown, 1985) and increases respiration (Aharoni, 1968) and the production of volatiles (Norman and Craft, 1968). While knowledge of the effects of ethylene on peel physiology is limited, early season peel disorders are often attributed by citrus handlers to prolonged ethylene exposure.

'Fallglo' is an early season tangerine that was released for commercial production in 1987 (Jackson, 1991). Florida fresh citrus packers have reported that 'Fallglo' is acutely susceptible to postharvest decay and peel disorders. This susceptibility has been attributed in part to the sensitivity of the peel to ethylene applied during degreening. Accordingly, packers have tested degreening strategies that yield acceptable peel color while minimizing conditions that may stimulate decay and peel disorders. One strategy has been to remove the fruit from the ethylene treatment before the fruit are fully degreened. This approach of under-degreening reduces the exposure time from several days to <1 day. Undergreening is reportedly effective because nonwaxed 'Fallglo' tangerine continue to degreen during subsequent storage.

The degreening characteristics of 'Fallglo' have not been previously documented. Since degreening may play a key role in postharvest marketing quality, we examined the effects of ethylene exposure time, waxing, and storage temperature on color development of 'Fallglo.'

Materials and Methods

Plant material

Mature 'Fallglo' were harvested at the Citrus Research and Education Center in Lake Alfred, Fla., or at a commercial grove

Fig. 1. Effect of ethylene exposure time on color and internal ethylene level of 'Fallglo.' Fruit were exposed to 5 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene (29.5 $\pm$ 2 °C, 93% $\pm$ 3% RH) for 0 (○), 2 (□), 6 (▲), 24 (●), or 48 h (■) and then stored at 0 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene (15.5 $\pm$ 1 °C, 93% $\pm$ 3% RH). Error bars represent SE of the means (n = 10 fruit).

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Fig. 2. Effect of ethylene exposure, waxing, and storage temperature on color and internal ethylene level of 'Fallglo.' Fruit were exposed to 0 (●, ○) or 5 (■, □) $\mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$, $93\% \pm 3\%$ RH) for 24 h and held at 0 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH) for 24 h. Fruit were waxed (closed symbol) or not waxed (open symbol) and stored at 4.5 (left) or $15.5 \pm 1^\circ\text{C}$ and $93\% \pm 3\%$ RH (right). Error bars represent SE of the means ($n = 10$ fruit).

near Haines City, Fla., from September to November 1995. Average fruit mass was about 225 g (range: 150 to 310 g) and diameter was about 8 cm at the midsection. Fruit were about 50% to 100% green (range of hue angles: 73 to 115°) before degreening.

Color, mass loss, and internal gas measurements

Color was measured by a $45^\circ/0^\circ$ D25-PC2 colorimeter (Hunter Associates Laboratory, Inc., Reston, Va.). Fruit color was measured at four regions along the midsection spaced 90° apart. L^* (0 = black, 100 = white), a^* , and b^* values were converted to chroma (0 = lowest intensity, 100 = greatest intensity), and hue angle (0° = red-purple, 90° = yellow, 180° = bluish-green, 270° = blue) according to McGuire (1992). Mass was measured after each color measurement. Mass loss was expressed as the percentage change in mass between measuring periods.

Internal gases were measured as previously described (Petracek

et al., 1995). Silicone (Silicon II; General Electric Co., Waterford, N.Y.) about 1 cm in diameter and 0.3 cm thick was applied to the stylar end of the fruit to create a gas sampling septum. Internal gas samples (0.5 mL) were taken from the core of the fruit through the septum by an insulin syringe equipped with a 7-mm needle. Samples were analyzed by a flow-through system consisting of O_2 and CO_2 analyzers connected in series with N_2 used as the carrier gas. Ethylene was analyzed by a gas chromatograph (GC) (5709A; Hewlett Packard, Wilmington, Del.) equipped with an activated alumina column and a flame ionization detector (minimum detectable ethylene level: $0.025 \mu\text{L}\cdot\text{L}^{-1}$).

Effect of ethylene exposure time, waxing, and storage temperature

EXPERIMENT 1. The effect of ethylene exposure time on color and internal ethylene level was examined. Fruit were harvested on 9 Oct. 1995 (average initial hue angle of 107°) and exposed to $5 \mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH) for 0, 2, 6, 24, or 48 h and then stored at 0 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene ($15.5 \pm 1^\circ\text{C}$ and $93\% \pm 3\%$ RH). Color and internal ethylene measurements were obtained before and 2 h after degreening and 3, 4, and 8 d after fruit ethylene exposure ($n = 10$ fruit). Fruit exposed for 0, 2, or 6 h were also measured 1 and 2 d after fruit ethylene exposure.

EXPERIMENT 2. The effects of ethylene exposure, waxing, and storage temperature on color and internal gas levels were examined. Fruit were harvested on 28 Sept. and 3 Oct. 1995 (average initial hue angles of 106° and 107° , respectively) and exposed to 0 or $5 \mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH) for 24 h and held at 0 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH) for 24 h. Fruit were waxed with a commercially available shellac-based wax or not waxed and stored at 4.5 or $15.5 \pm 1^\circ\text{C}$ and $93\% \pm 3\%$ RH. Fruit color, mass, and internal ethylene measurements were obtained 0, 3, 9, and 15 d after harvest ($n = 10$ fruit). Since similar results were obtained for the two harvests, only the results from the second harvest are presented.

EXPERIMENT 3. The effects of ethylene exposure, waxing, and storage temperature on color and mass loss were determined in a more detailed study. Fruit were harvested 21 Oct. 1995 and divided into early and later stages of color break based on visual observation (average initial hue angles of 97° and 85° , respectively). Fruit were exposed to $5 \mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH) for 0, 8, or 24 h and held at 0 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH) for 48, 40, or 24 h, respectively. Fruit were then either not waxed or waxed and stored at 4.5, 15.5, or $26.5 \pm 1^\circ\text{C}$ and $93\% \pm 3\%$ RH. Fruit were also waxed after 96 h of storage at 15.5°C (delayed wax). Color and mass measurements were obtained 0, 2, 6, 13, and 20 d after harvest ($n = 10$ fruit).

EXPERIMENT 4. Fruit were harvested 13 Nov. 1995 and were either waxed or not waxed. Fruit were stored at 4.5, 15.5, or 26.5°C . Internal O_2 and CO_2 levels were measured 24 h after waxing ($n = 10$ fruit).

Statistical design and analysis

Treatments for all four experiments were organized in a com-

pletely randomized factorial design and data were analyzed by ANOVA ($p < 0.05$).

Results

Degreening of 'Fallglo' was characterized by increased brightness (L^*) and intensity (chroma) and decreased hue angle (Figs. 1–3). 'Fallglo' color often varied greatly over the surface of the fruit. Color of adjacent regions of fruit in the early to later stages of degreening were often sharply distinct (e.g., green next to yellow-orange) and thus had a patchy appearance. The average difference in hue angle of adjacent regions was about 11° with a maximum difference of 38° (77 to 115°). As the fruit progressed from the early stages of color break (hue angle of about 95 to 115°) to fully degreened (hue angle $<80^\circ$), average differences in hue angle of adjacent regions decreased to about 6° .

EXPERIMENT 1. Exposure of 'Fallglo' to ethylene for 24 or 48 h stimulated degreening (Fig. 1). Fruit exposed for 48 h were degreened at the end of the exposure period while fruit exposed for 24 h required several additional days beyond the exposure period to degreen. The color of fruit exposed for 2 or 6 h was similar to that of fruit not exposed to ethylene (nonexposed). However, fruit from all treatments in this experiment degreened over an 8-d period.

Internal ethylene levels were low ($<0.15 \mu\text{L}\cdot\text{L}^{-1}$) or undetectable 2 h after ethylene exposure (Fig. 1). Ethylene levels of fruit exposed 24 or 48 h increased after several days following exposure, while levels in fruit exposed for 2 or 6 h or nonexposed fruit remained low. Increasing ethylene levels were not associated with visible symptoms of fruit decay.

EXPERIMENT 2. As in the previous experiment, exposure of 'Fallglo' to ethylene for 24 h stimulated degreening (Fig. 2). Furthermore, waxing and low-temperature storage (4.5°C) slowed degreening of fruit that had not been exposed to ethylene. Degreening of nonexposed, nonwaxed fruit continued during storage at 15.5°C . After 7 d in storage, the color of these fruit was similar to that of fruit exposed to ethylene for 24 h.

Internal ethylene levels of exposed fruit increased regardless of storage temperature (Fig. 2). Ethylene levels also increased for nonexposed fruit that had been waxed and stored at 15.5°C . However, ethylene levels of nonexposed, nonwaxed fruit did not increase regardless of storage temperature.

EXPERIMENT 3. In general, waxing or low-temperature storage (4.5°C) hindered degreening of nonexposed fruit that were harvested at early (Fig. 3) or later (Fig. 4) stages of color break. High temperature storage (26.5°C) also hindered degreening compared to

fruit stored at 15.5°C . The dependence of hue angle on ethylene exposure time was apparent for fruit stored at 4.5 or 26.5°C , but was less evident for fruit stored at 15.5°C at which temperature most fruit had degreened regardless of ethylene treatment.

The effect of delayed waxing (waxing after the day 6 measurement) is illustrated in the degreening time course for nonexposed fruit (Fig. 5). As in Expt. 2, waxing and low-temperature storage (4.5°C) tended to impede color change as indicated by hue angle. High-temperature storage (26.5°C) also reduced changes in hue angle during storage. As expected, nonwaxed and delayed-waxed fruit had similar color until after the day 6 measurement. Delayed waxing increased L^* and reduced chroma for fruit stored at 4.5 , 15.5 , and 26.5°C and decelerated the decrease in hue angle for fruit stored at 15.5 and 26.5°C .

In general, mass loss was reduced slightly by waxing, but was reduced greatly by decreasing storage temperature (Fig. 6). Stage of color break and ethylene exposure did not affect mass loss. Similar results were found in Expt. 2 and were consistent throughout storage (data not shown).

EXPERIMENT 4. Internal O_2 levels decreased and CO_2 levels increased as a result of either waxing or increasing storage tem-

Fig. 3. Effect of ethylene exposure, waxing, and storage temperature on color of 'Fallglo' 20 d after fruit ethylene exposure. Fruit harvested at the early stage of color break were exposed to $5 \mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\% \text{RH}$) for 0 (white bar), 8 (light gray bar), or 24 h (dark gray bar) and held for 48, 40, or 24 h, respectively, at $29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\% \text{RH}$. Fruit were then either not waxed or waxed and stored at 4.5 (left), 15.5 (center), or $26.5 \pm 1^\circ\text{C}$ (right) and $93\% \pm 3\% \text{RH}$. Fruit were also waxed after 96 h of storage (delayed wax). Error bars represent SE of the means ($n = 10$ fruit). Interactions between ethylene exposure and storage temperature and waxing and storage temperature were significant for all three color elements ($p < 0.01$). Main treatment effects were significant for all three color elements except for the effect of storage temperature on chroma.

Fig. 4. Effect of ethylene exposure, waxing, and storage temperature on color of 'Fallglo' 20 d after fruit ethylene exposure. Fruit harvested at the later stage of color break were exposed to 5 $\mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH) for 0 (white bar), 8 (light gray bar), or 24 h (dark gray bar) and held for 48, 40, or 24 h, respectively, at $29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH. Fruit were then either not waxed or waxed and stored at 4.5 (left), 15.5 (center), or $26.5 \pm 1^\circ\text{C}$ (right) and $93\% \pm 3\%$ RH. Fruit were also waxed after 96 h of storage at 15.5°C (delayed wax). Error bars represent SE of the means ($n = 10$ fruit). Interactions between storage temperature and ethylene and storage temperature and waxing and main treatment effects were significant ($p < 0.01$).

Fig. 5. Effect of delayed waxing and storage temperature on color of 'Fallglo.' Fruit not exposed to ethylene were held for 48 h ($29.5 \pm 2^\circ\text{C}$, $93\% \pm 3\%$ RH) after harvest and then were either not waxed ($\circ$) or waxed ($\bullet$) and stored at 4.5 (left), 15.5 (center), or $26.5 \pm 1^\circ\text{C}$ (right) and $93\% \pm 3\%$ RH. Fruit were also waxed 96 h after storage (*). Error bars represent SE of the means ($n = 10$ fruit).

Fig. 6. Effect of ethylene exposure, waxing, and storage temperature on mass loss of 'Fallglo' between 13 and 20 d after fruit ethylene exposure. Fruit harvested at the early (top) or later (bottom) stages of color break were exposed to $5 \mu\text{L}\cdot\text{L}^{-1}$ ethylene ($29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH) for 0 (white bar), 8 (light gray bar), or 24 h (dark gray bar) and held for 48, 40, or 24 h, respectively, at $29.5 \pm 2^\circ\text{C}$ and $93\% \pm 3\%$ RH. Fruit were then either not waxed or waxed and stored at 4.5°C (left), 15.5°C (center), or $26.5 \pm 1^\circ\text{C}$ (right) and $93\% \pm 3\%$ RH. Fruit were also waxed after 96 h of storage (delayed wax). Error bars represent SE of the means ($n = 10$ fruit). Main treatment effects of waxing and storage temperature were significant for mass of fruit at early and later stages of color break ($p < 0.001$).

perature (Table 1). For example, internal O_2 and CO_2 levels were 18.7% and 1.2%, respectively, for nonwaxed fruit and 4.5% and 6.6%, respectively, for waxed fruit stored at 15.5°C .

Discussion

'Fallglo' tangerine is a relatively new cultivar that has been handled commercially for only several seasons. Strategies for handling 'Fallglo' have been based on approaches used for other varieties and have been adapted through trial and error. During the initial seasons, 'Fallglo' were often exposed to ethylene until they were virtually without green pigmentation. This approach was used because other citrus varieties, such as 'Hamlin' orange, require ethylene exposure throughout the degreening process (Grierson and Newhall 1960). While long-term ethylene treatments (up to 5 d for green fruit) effectively degreened 'Fallglo,' the peel sometimes degraded within several days after exposure due to physiological and pathological disorders.

Suspensions that ethylene exposure caused these disorders led some packers to reduce or eliminate ethylene exposure. Among the intriguing results of their efforts, packers reported receiving compliments rather than complaints about fruit shipped in the early stages of color break. Receivers reported very little green remaining in the peel as a result of color change during shipping. Our results confirm that the color of 'Fallglo' changes without or after ethylene exposure (Figs. 1–4). For example, fruit that were in the very early stages of color break ($>95\%$ green) eventually degreened without ethylene exposure over 8 d in storage at 15.5°C (Fig. 1). We had anticipated that ethylene exposure for 2 or 6 h would accelerate degreening. In contrast to reports from packers, these short exposure periods did not hasten color change.

The degreening of 'Fallglo' without ethylene exposure is not understood. We had initially suspected that degreening of nonexposed fruit was caused by high internal ethylene levels. However, ethylene levels remained low ($< 0.10 \mu\text{L}\cdot\text{L}^{-1}$) or were undetectable in nonexposed, nonwaxed fruit throughout storage (Figs. 1 and 2). Regardless of the cause, the degreening of nonexposed fruit is apparently temperature sensitive since color change of fruit stored at low (4.5°C) and high (26.5°C) temperatures developed more slowly than in fruit stored at 15.5°C (Fig. 3–5).

The relationship between postexposure internal ethylene levels and degreening of nonwaxed 'Fallglo' is intriguing. Ethylene levels after exposure increased only when the exposure period was sufficient to accelerate color change (24 or 48 h exposure, Fig. 1; 24 h exposure, nonwaxed, 15.5°C storage, Fig. 2). In contrast, previous studies in our laboratory showed that white grapefruit, 'Hamlin' oranges, and 'Orlando' tangelos degreened after 24 h exposure to ethylene, but internal ethylene levels remained low during 7 d of subsequent storage (unpublished data). These results suggest that the degreening process and autocatalytic-like ethylene production of 'Fallglo' may be unique and perhaps related. The nature of the increase in ethylene level and its potential effect on peel degradation requires further investigation.

The rate of degreening during storage of nonexposed fruit was greatest when the fruit were not waxed and stored at 15.5°C (Figs. 2–4). The effects of waxing and storage temperature on degreening may be controlled by two separate mechanisms. Waxing of nonexposed fruit that were stored at 15.5°C increased ethylene levels (Fig. 2), but also decreased internal O_2 and increased internal CO_2 (Table 1). Since CO_2 impedes degreening (Grierson et al. 1986) and ethylene action (Beyer et al. 1984), the effect of high internal ethylene levels on degreening of waxed fruit may be negated. However, preliminary studies in our laboratory using controlled-atmosphere storage suggest that low O_2 (4%) rather than high CO_2 (8%) inhibits degreening of 'Fallglo' (unpublished data).

Low-temperature storage (4.5°C) effects on degreening of nonexposed fruit are not likely to be related to internal gas level

Table 1. Effect of storage temperature and waxing on internal gas levels.^z

Storage temp ($^\circ\text{C}$)	Wax application	Internal gas level (%)	
		O_2	CO_2
4.5	+	15.5 ± 0.4	1.6 ± 0.2
15.5	+	4.5 ± 0.2	6.6 ± 0.2
26.5	+	3.7 ± 0.3	6.9 ± 0.3
4.5	–	19.3 ± 0.5	0.9 ± 0.1
15.5	–	18.7 ± 0.4	1.2 ± 0.1
26.5	–	18.8 ± 0.3	1.3 ± 0.2

^zGas levels were measured after 24 h of storage. Values represent mean ($\pm$ SE) for 10 fruit. Main treatment effects of storage temperature and waxing were significant for O_2 and CO_2 levels ($p < 0.001$).

since ethylene (Fig. 2), O₂, and CO₂ (Table 1) levels were similar for nonexposed, nonwaxed fruit stored at 4.5 and 15.5 °C. Temperature effects on degreening of nonexposed 'Fallglo' may instead be related to enzyme kinetics. However, we note that degreening was slower at both low (4.5 °C) and high (26.5 °C) temperatures than at 15.5 °C (Figs. 2–4). The apparent high-temperature sensitivity is of interest, particularly since other citrus varieties are held at 29.5 °C during commercial degreening.

The degreening characteristics of 'Fallglo' are not without precedence among other varieties. For example, low (10 °C) and high (21 °C) temperature and wax application hinder degreening of Sicilian lemons (Oberbacher et al. 1961). Grierson and Newhall (1960) showed that 'Duncan' white grapefruit and 'Valencia' orange degreen after ethylene exposure. Oberbacher et al. (1962) reported that green, nonwaxed 'Marsh' white grapefruit degreen during a 20 d shipping period. The sensitivity of 'Fallglo' to the effects of postharvest treatment may make it a useful model for further developing our understanding of the physiology of degreening.

From a practical perspective, the degreening of 'Fallglo' may be best achieved by partially degreening the fruit with ethylene exposure and holding the fruit at 15.5 °C at high humidity after exposure to permit more color change, while reducing mass loss. After the fruit have progressed through the later stage of color break (hue angle <85°), the fruit can then be waxed and placed in low-temperature storage (4.5 °C). Since waxing and low-temperature storage (4.5 °C) reduce color change (Figs. 2–4), there is no advantage to storing waxed fruit at high temperature (26.5 °C, Figs. 3 and 4). Furthermore, low-temperature storage of waxed 'Fallglo' is preferable since waxing and high-temperature storage stimulate postharvest pitting (unpublished data).

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