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A POSTHARVEST PITTING OF TEMPLE ORANGES STIMULATED BY HIGH TEMPERATURE STORAGE AND WAX APPLICATION

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Abstract. **The morphology and etiology of a postharvest peel disorder of Temple oranges resulting from an apparent collapse of oil glands were determined. The disorder was stimulated by high temperature storage (21°C) and wax application. Symptoms were less pronounced in fruit coated with waxes that resulted in higher internal O_2 levels or lower internal CO_2, ethanol, or acetaldehyde levels. This disorder is similar to one observed in white grapefruit, Fallglo tangerine, and navel orange, but the severity is less pronounced in Temples.**

Temple oranges (*Citrus reticulata* Blanco × *C. sinensis* L.) are probable tangors that are marketed as oranges. They were introduced from Jamaica to Florida in 1896 after the freezes of the 1895-96 season and were publicly released in 1919 (Jackson, 1991). While Temples are noted for their high internal quality, production and handling problems have, in part, limited their acceptance by the citrus industry. Among postharvest handling problems is their hypersensitivity to ethylene at degreening, resulting in a blackening of the peel (Grierson and Newhall, 1953) and stem end rot (Grierson and Newhall, 1955). Delayed handling and degreening under low humidity have been shown to aggravate the effect of ethylene (McCornack, 1972). While the effects of controlled or modified atmospheres on peel disorders have not been fully documented, Chace (1969) noted that controlled atmosphere storage improved the flavor of Temples. Moreover, the influence of the currently-used water wax formulations on the storage of Temples has not been previously examined.

"Postharvest pitting" of citrus peel is a disorder characterized by the collapse of oil glands that occurs during the early weeks of storage (Petracek et al., 1995; Petracek and Davis, 1996; Petracek et al., 1997; Petracek et al., 1998). Wax application and high temperature storage trigger pitting, reduce internal O_2 levels, and increase internal CO_2 levels. Fruit stored in low O_2 (4%) develop pits thus suggesting that pitting is a symptom of hypoxia (Petracek, unpublished).

Postharvest pitting has been studied in white grapefruit, California navel oranges, and Fallglo tangerines (Petracek et al., 1997). Our interest in examining postharvest pitting of Temples came from the observation that Fallglo, a variety with Temple parentage (Bower citrus hybrid [*Citrus reticulata* Blanco × (*C. reticulata* Blanco × *C. paradisi* Macf.)] × Temple [*C. reticulata* Blanco × *C. sinensis* L.]), are exceedingly susceptible to pitting with up to 96% of waxed fruit stored three weeks at 21°C showing symptoms of the disorder (Petracek et al., 1998). Thus, we decided to determine if (1) the reportedly poor handling characteristics of Temples are expressed as a susceptibility to postharvest pitting and (2) Temples would be a suitable model for further study of pitting.

Materials and Methods

Plant material. Mature Temples for the first and second experiments were harvested from commercial groves in Polk County, Fla. on 13 Jan. and 3 Feb. 1997, respectively, and were transported to the Citrus Research and Education Center (CREC), Lake Alfred, Fla, stored overnight at 21 ± 1°C and 93 ± 2% R.H., and packed the next day. Mature fruit for the third experiment were harvested from the teaching block at the

CREC on 4 Feb. 1997 and packed the same day. Fruit were washed on roller brushes with Fruit Cleaner 395 (FMC, Lakeland, Fla.) before wax application. Fruit were not degreened and fungicides were not used.

Experiment 1. The effect of wax formulation on pitting and internal O_2 was determined. Fruit were either not waxed or waxed with (1) shellac-based water waxes from FMC or Elf Atochem (Monrovia, Calif.) randomly designated as shellac 1 or 2, (2) carnauba-based water waxes from FMC or Elf Atochem randomly designated as carnauba 1, 2, 3, or 4, or (3) polyethylene-based water waxes from FMC designated as polyethylene 1 or 2. Fruit were also coated with combination waxes consisting of shellac/wood resin (65:35), wood resin/shellac (90:10), carnauba/wood resin (70:30), or carnauba/shellac (80:20; Elf Atochem). Fruit were stored at 21 ± 1°C and 93 ± 2% RH.

Internal O_2 and CO_2 samples were taken from the core of the fruit through a silicone septum applied to the stylar end of the fruit as described previously (Petracek et al., 1995). Internal gas sampling through the stylar end to the air space of the core of Temples was often obstructed by pulp or other tissues (> 25% of sampled fruit). In these cases, internal gas samples were taken through a silicone septum applied at the stem end. Gas samples were evaluated 1 day after wax application (n = 10 fruit per treatment). Pitting, resulting from the targeted collapse of oil glands without the presence of wound periderm, was determined by visual inspection 13 days after wax application (n = 3 cartons of 20 fruit).

Experiment 2. The effect of wax formulation on pitting, internal gas level, shine, and weight loss was determined. Fruit were either not waxed or waxed with (1) shellac-based water waxes from FMC or Elf Atochem randomly designated as shellac 1, 2, or 3, (2) polyethylene-based water waxes from FMC designated as polyethylene 1 or 2, or (3) beeswax. Fruit were also coated with combination waxes consisting of wood resin/shellac (90:10), carnauba/wood resin (70:30), or carnauba/shellac (80:20) from Elf Atochem. Fruit were stored at 21 ± 1°C and 93 ± 2% RH.

Internal O_2 and CO_2 were evaluated 1 and 9 days after wax application by the method described above. Internal ethanol and acetaldehyde were determined 16 days after wax application by a GC (5709A, Hewlett Packard, Wilmington, Del.) equipped with a HayeSep Q Custom (1.8 m x 3.175 mm, 100/120) column (Supelco, Bellefonte, Pa.), and a flame ionization detector. Shine was determined 1 and 16 days after wax application (gloss measured at 60° to the vertical by a Model Micro-Tri-gloss meter, BYK Gardner, Silver Springs, Md.). Weight loss was determined by weighing the fruit 0, 7, and 12 days after wax application and expressed as percent lost per day. Pitting was determined by visual inspection 24 days after wax application (n = 3 cartons of 30 fruit per treatment). All other measurements were based on 10 fruit per treatment.

Experiment 3. The effects of storage temperature and wax application on pitting of Temples was determined. Fruit were either not waxed or waxed with a shellac-based water wax (FMC) and stored at 5, 13, or 21°C, RH 90 to 95%. Additional waxed fruit were stored at 21°C and transferred to 5°C after 24, 48, 96, or 192 h. The time required to attain an 87% reduction in internal pulp temperature of fruit packed in a carton (i.e. reduction from 21 to 7°C) was about 9h as determined by thermocouple measurement (not shown). Internal O_2 and CO_2 were evaluated 2 and 25 days after wax application by the method described above for fruit stored at constant temperature only (n = 10 fruit per treatment). Pitting was determined by visual inspection 20 days after wax application (n = 3 cartons of 20 fruit per treatment).

Results and Discussion

"Postharvest pitting" of Temples was characterized by the collapse of oil glands that developed within a week after wax application and high temperature storage. The oil glands tended to collapse in clusters of 1 to 70 oil glands with an average of 6 glands per cluster and 2 clusters per fruit. The collapse was similar to that observed for white grapefruit (Petracek et al., 1995), Fallglo tangerine (Petracek et al., 1998), and California navel orange (Petracek et al., 1997) in that the first and most affected area was the region associated with the oil gland and the deep depression of that region.

However, several differences between pitting of Temples and the other varieties were observed. In pitting of white grapefruit and Fallglo, collapse of the regions between the oil glands tended to occur as a secondary process that was often separated by several days from the initial collapse of the oil glands. In Temples and navels (Petracek, unpublished), collapse between the cells was often concurrent with the collapse of the oil glands. The collapse of regions surrounding the oil glands imparted a more angular appearance to the collapsed cluster than observed for white grapefruit and Fallglo. Similar to Fallglo (Petracek et al., 1998) and navels (Petracek, unpublished), pitting of Temples was typically found from the midsection to stem end of the fruit. In contrast, more pitting was observed at the stylar than the stem end of white grapefruit (Petracek and Davis, 1996).

Pitting of Temples was less severe than pitting observed previously in other varieties of citrus. Incidences of pitting of white grapefruit, Fallglo, and navel oranges tend to be higher than that of Temples. Pitting of Fallglo, for example, typically occurs at incidence rates >30% for waxed fruit stored at 21°C (Petracek et al., 1998) compared with < 30% incidence rates in Temples. The extent of pitting (i.e. the number of col-

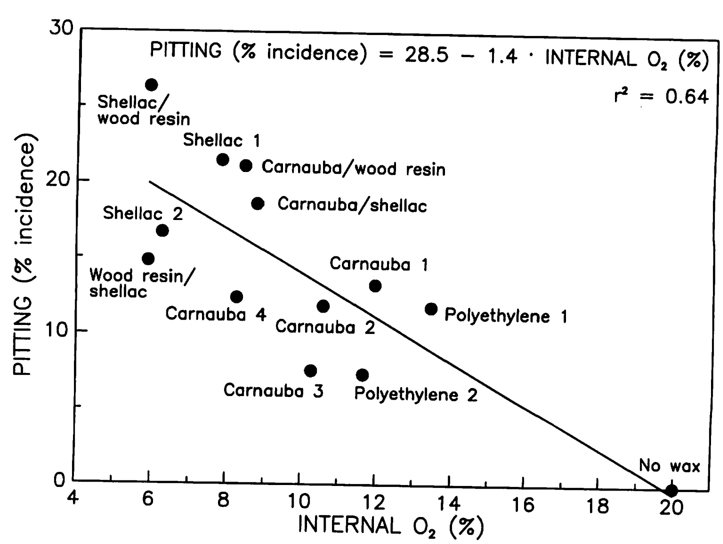

Figure 1. Experiment 1: Influence of wax formulation on internal O_2 and postharvest pitting incidence of Temples. Fruit were waxed and stored at 21 ± 1°C and 93 ± 2% RH. Internal O_2 was evaluated 1 day after wax application (n = 10 fruit per treatment). Pitting was evaluated 13 days after wax application (n = 3 cartons of 20 fruit per treatment).

Table 1. Experiment 2: Effect of wax formulation on postharvest storage of Temples.[z]

	Pitting (%)	Internal O_2 (%)		Internal CO_2 (%)		Internal ethanol (%)	Internal acetaldehyde (%)	Shine (Gloss units)		Weight loss (%/day)	
Wax	Day 24	Day 1	Day 9	Day 1	Day 9	Day 16	Day 16	Day 1	Day 16	Day 0 to 7	Day 7 to 12
No wax	0a	18.2d	18.2e	2.2a	1.7a	0.00a	0.00a	4.6a	2.7a	0.48d	0.26c
Shellac 1	8ab	6.9a	12.2cd	5.5b	3.7b	0.09a	0.01ab	5.0a	4.5bc	0.35ab	0.21abc
Shellac 2	16bcd	11.6c	7.0ab	7.5cd	7.5e	0.72bcd	0.02abc	5.0a	4.5bc	0.37ab	0.21abc
Shellac 3	27e	5.4a	6.2a	7.8d	7.2e	1.12d	0.04cd	5.7b	4.5bc	0.39b	0.26bc
Wood resin/shellac	22de	9.4b	12.9d	5.4b	4.2bc	0.07a	0.02abc	4.9a	4.7c	0.32a	0.17a
Carnauba/shellac	18cde	9.4b	5.6a	7.9d	6.1de	0.41abc	0.03bc	5.1ab	4.7c	0.38ab	0.19a
Carnauba/wood resin	23de	5.9a	8.3b	7.5cd	6.8e	0.79cd	0.06d	5.0a	4.8c	0.35ab	0.20a
Beeswax	11abc	6.8a	10.8c	5.8b	3.7b	0.27abc	0.03bc	4.8a	4.5bc	0.40bc	0.21abc
Polyethylene 1	16bcd	5.2a	5.5a	7.4cd	5.3cd	0.25ab	0.01abc	4.8a	4.6bc	0.30ab	0.20ab
Polyethylene 2	8ab	6.8a	13.4d	6.2bc	2.9ab	0.09a	0.00a	5.0a	4.2b	0.36ab	0.21abc

[z]Pitting was determined as the percent of fruit with oil gland collapse 24 days after wax application and storage at 21°C and 93% RH (n = 3 cartons of 30 fruit per treatment). Internal gas levels, shine, and weight loss were determined during storage (n = 10 fruit per treatment). Mean separation within each column is by Duncan's New Multiple Range (α = 0.05).

lapsed oil glands) also tends to be greater in Fallglo, white grapefruit, and navel orange.

Experiment 1: In the first formulation study, pitting incidence of fruit stored at 21°C increased with decreasing internal O_2 levels ($r = -0.80$, $r^2 = 0.64$; Fig. 1). Correlation between pitting incidence and internal CO_2 levels was not significant ($r = 0.47$, $r^2 = 0.22$; data not shown). Fruit coated with shellac-based or combination waxes containing shellac or wood resin tended to have higher pitting incidences and lower internal O_2 levels than fruit coated with carnauba-based or polyethylene-based waxes which are more permeable to gases (Hagenmaier and Baker, 1993; Hagenmaier and Shaw, 1992). Fruit that were not coated had high internal O_2 levels and did not pit. The correlation between high pitting incidence and low internal O_2 levels has been observed previously in white grapefruit (Petracek et al., 1995; Petracek, 1996) and Fallglo (Petracek et al., 1998).

Experiment 2: In the second formulation study, pitting incidence tended to increase with decreasing internal O_2 levels and increasing internal CO_2, ethanol, and acetaldehyde levels, and increasing shine (Tables 1 and 2). Fruit that were not coated did not pit and had the highest internal O_2 levels and rates of weight loss and had the lowest internal CO_2, ethanol, and acetaldehyde levels and the lowest shine. Results on the influence of wax formulation on internal gas and weight loss tended to support an observation by the industry that coatings with higher shine have poorer gas exchange (Table 2).

Experiment 3: In the study on the effects of storage temperature and wax application, pitting incidence and internal CO_2 levels of fruit tended to increase and internal O_2 levels tended to decrease with wax application or increasing storage temperature (Table 3). Transferring the fruit from high temperature (21°C) to low temperature (5°C) after 24 to 192 h did not significantly reduce the incidence of pitting. In comparison, transferring white grapefruit or Fallglo from 21°C to 5°C after 2 or 3 days, respectively, reduced pitting incidence (Petracek et al., 1995; Petracek et al., 1998).

Conclusions

"Postharvest pitting" of Temples is similar to that of white grapefruit, Fallglo tangerines, and California navel oranges in that the disorder is characterized by the collapse of oil glands and is stimulated by wax application and low temperature storage. Furthermore, coatings that are reportedly more permeable to gases (Hagenmaier and Baker, 1993; Hagenmaier and Shaw, 1992) and consequently resulted in higher internal O_2 levels and lower internal CO_2, ethanol, and acetaldehyde tended to show fewer symptoms. This suggests a role for gas exchange in stimulating pitting. In contrast with the other varieties, however, pitting of Temples was not reduced by a transfer to low temperature storage at 24 after wax application. Finally, we note that pitting of Temples was less severe and internal gas samples were more difficult to take than for

Table 2. Experiment 2: Correlation coefficients among characteristics measured for Temples.[z]

	Pitting	O_2		CO_2		Ethanol	Acetaldehyde	Shine		Weight loss	
	Day 24	Day 1	Day 9	Day 1	Day 9	Day 16	Day 16	Day 1	Day 16	Day 0 to 7	Day 7 to 12
Pitting	1.00										
O_2: day 1	-0.51	1.00									
O_2: day 9	-0.70*	0.60*	1.00								
CO_2: day 1	0.73**	-0.72**	-0.94***	1.00							
CO_2: day 9	0.81**	-0.41	-0.89***	0.87***	1.00						
Ethanol	0.74**	-0.35	-0.69*	0.69*	0.87***	1.00					
Acetaldehyde	0.75**	-0.45	-0.62*	0.63*	0.75**	0.79**	1.00				
Shine: day 1	0.64*	-0.52	-0.56	0.65*	0.63*	0.76**	0.43	1.00			
Shine: day 16	0.72**	-0.79**	-0.75**	0.84***	0.67*	0.41	0.59*	0.45	1.00		
Weight loss: day 0 to 7	-0.52	0.68*	0.42	-0.60*	-0.38	-0.07	-0.22	-0.22	-0.83***	1.00	
Weight loss: day 7 to 12	-0.31	0.39	0.27	-0.39	-0.19	0.21	-0.20	0.21	-0.72**	0.82**	1.00

[z]Multiple regression analysis was performed on data in table 2. Significance: * = 0.05, ** = 0.01, and *** = 0.001.

Table 3. Experiment 3: Effect of storage temperature and wax application on pitting of Temples.[z]

Storage temperature (°C)	Waxing	Transfer to 5°C (40°F)	Pitting (%)	Internal O_2 (%)		Internal CO_2 (%)	
			Day 20	Day 2	Day 25	Day 2	Day 25
5 (40°F)	-	None	0a	19.9	18.7	0.6	0.9
13 (55°F)	-	None	2ab	19.6	17.9	1.4	1.6
21 (70°F)	-	None	0a	18.6	18.0	1.9	1.2
5 (40°F)	+	None	2ab	15.0	17.5	3.0	4.6
13 (55°F)	+	None	3ab	6.2	6.9	4.9	5.6
21 (70°F)	+	None	16c	6.2	6.6	5.7	6.9
21 (70°F)	+	After 24 h	12bc				
21 (70°F)	+	After 48 h	12bc				
21 (70°F)	+	After 96 h	10abc				
21 (70°F)	+	After 192 h	12bc				

[z]Pitting incidence was determined on 20 days after wax application (n = 3 cartons of 20 fruit per treatment). Internal gas levels were determined 2 and 25 days after wax application (n = 10 fruit per treatment). Mean separation for pitting was by Duncan's New Multiple Range ($\alpha = 0.05$). Interactions of storage temperature and wax application and main treatment effects were significant ($\alpha = 0.01$) for internal O_2 levels at day 2 and internal CO_2 levels at days 2 and 25. Main treatment effect of wax application on internal O_2 levels at day 25 was significant ($\alpha = 0.01$).

the other varieties. Thus Temples may not serve as a good model variety for further studies on pitting.

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