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The flavor of mandarin hybrids with different coatings☆

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Abstract

Mandarin hybrids were treated with wax and resin coatings having differing oxygen permeabilities. After storage for 7 days at 21 °C, fruit with coatings having O_2 permeability $\leq 1.1 \times 10^{-16}$ mol m s^{-1} m^{-2} Pa^{-1} were rated by a sensory panel as markedly less fresh than fruit with higher permeability coatings. These low-permeability coatings were those composed mainly of shellac and wood resin. The flavor changed most for fruit having mean internal $O_2 < 4\%$, internal $CO_2 > 14\%$ at 21 °C and juice ethanol content > 1500 ppm after 7 days storage at that temperature. All coatings seemed suitable for storage of specialty citrus fruit for 7 days at 5 °C. It is recommended that for mandarin hybrids, the most suitable are those composed mainly of waxes rather than shellac or wood resin. Published by Elsevier Science B.V.

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1. Introduction

It is well-known that when plant tissue is exposed to anaerobic conditions, ethanol accumulates and a 'fermented' flavor develops (Blanpied, 1990). Mandarin fruit and their hybrids are known to sometimes show similar effects under normal storage conditions with some commonly used citrus coatings, especially the less permeable coatings containing large amounts of shellac and wood resin (Ahmad and Khan, 1987; Cohen et al., 1990; Shaw et al., 1992; Hagenmaier and Baker, 1994; Mannheim and Soffer, 1996). Such coatings tend to overly restrict the exchange of O_2 and CO_2 between atmosphere and fruit to the extent that internal O_2 concentration becomes too low to sufficiently support aerobic respiration, resulting in high values of internal ethanol, acetaldehyde and internal CO_2. Similar effects have also been observed with citrus fruit stored under controlled atmosphere conditions (Hatton and Spalding, 1990; Ke and Kader, 1990).

The purpose of the present study was to observe how some experimental coatings compare with commercial, resin-based coatings with respect to their influence on sensory flavor and appearance of mandarin hybrids, in order to find

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criteria for selection of coatings with suitable O_2 permeability. Our methodology was to determine how O_2 permeability of the coating relates to fruit quality as measured by flavor panel, interior gas of the fruit and ethanol content.

2. Materials and methods

2.1. Sample preparation

The citrus varieties included in this study were the Temple orange or tangor, the Dancy tangerine, the Orlando tangelo, the Nova tangelo, the Robinson tangerine, the Sunburst tangerine, the Murcott (or Honey) tangerine and the Fallglo tangerine from packinghouses in Lake Alfred and Winter Haven, FL harvested October 1998 to February 1999 (Table 1), taken from field boxes after ethylene degreening (if used) and transported to our research laboratory for application of coatings the same day. In addition, a sample of fruit packed at the packinghouse was taken off the processing line. Before application of coatings, the fruit were washed on rotary brushes, using Decco Fruit and Vegetable Kleen 241 (Elf Atochem, Monrovia, CA) and dipped in 1000 ppm imazilil (Fungaflor 500EC, Janssen Pharmaceutica, Titusville, NJ). About 0.3 g of coating was spread on each piece of fruit by hand (latex gloves) and dried in a forced-air dryer at 49 °C, residence time 5 min.

For purposes of comparison, samples of tangelos and Sunburst tangerines coated in Florida packinghouses were obtained from three local supermarkets on December 22 (harvest date unknown). Mean temperature at time of purchase was 18 °C. They were kept at 21 °C for 24 h before analysis of internal gases.

The Primafresh HS (Formula Corp., Seattle, WA), the Britex 555 (Brogdex Co., Pomona, CA) and the Shellac-Resin were commercial citrus coatings (Table 2). The three experimental coatings (B, C and E, Table 2) were formulated in our laboratory. The wax portions of the experimental coatings were made as described earlier (Hagen-

Table 1
Dates of experiments, fruit varieties, ethylene treatments, values at day zero of acid, Brix-acid ratios (BAR) and coatings used at packinghouse for each experiment

Trial[a]	Date[b]	Variety	C_2H_4[c]	Acid (%)[d]	BAR[e]	H[f] coating
Fg2	Oct. 1	Fallglo	Yes	1.16	9.6	FMC 4285
Fg6	Oct. 28	Fallglo	Yes	1.01	11.4	FMC 4285
Rb5	Oct. 28	Robinson	Yes	1.02	11.0	FMC 4285
Sb2	Nov. 12	Sunburst	No	1.14	10.1	Unknown
Sb4	Nov. 24	Sunburst	No	1.24	10.0	FMC 410
Sb9	Dec. 30	Sunburst	No	1.03	12.0	FMC 410
Dn8	Jan. 20	Dancy	No	1.12	10.0	FMC 4201
Mr4	Feb. 3	Murcott	No	0.95	12.3	FMC 410
Mr6	Feb. 23	Murcott	No	1.05	12.3	FMC 4201
Nv2	Nov. 12	Nova	Yes	0.87	13.5	Unknown
Nv4	Nov. 24	Nova	Yes	0.82	14.7	FMC 410
Or3	Dec. 9	Orlando	Yes	0.79	15.6	Unknown
Or6	Dec. 30	Orlando	No	0.92	13.9	FMC 410
Tm6	Feb. 3	Temple	No	1.03	11.0	FMC 410
Tm8	Feb. 23	Temple	No	1.12	12.5	FMC 4201

[a] The number included in the name indicates harvest time in weeks since the first 1% of that variety was packed.
[b] Experiment start date (1998–1999 season).
[c] Indicates whether or not ethylene was used to degreen the fruit.
[d] Acid content of the juice (anhydrous citric acid equivalent) at start of experiment.
[e] The Brix-acid ratio of the juice at start of experiment.
[f] Coatings applied in the packinghouse for treatment 'H'.

Table 2
Coating and storage treatments[a]

	Coating	Oxygen permeability of coating at 30 °C (mol m s^{-1} m^{-1} Pa^{-1})	Storage conditions
Z	None	–	Not stored
G5	Shellac-Resin	0.6×10^{-16}	5 °C, 7 days
A	None	–	21 °C, 7 days
B	Pe–cand	14×10^{-16}	21 °C, 7 days
C	Pe	100×10^{-16}	21 °C, 7 days
D	Primafresh HS	11×10^{-16}	21 °C, 7 days
E	Pe-shellac-cand	10×10^{-16}	21 °C, 7 days
F	Britex 555	1.1×10^{-16}	21 °C, 7 days
G	Shellac-resin	0.6×10^{-16}	21 °CC, 7 days
H	Table 1		21 °CC, 7 days

[a] Pe, polyethylene wax; cand, candelilla wax.

maier, 1998). The polyethylene coating (C, Table 2) contained 18.3% polyethylene wax (AC629, Allied Signal, Morristown, NJ), 3.7% oleic acid (Emersol 6321 from Henkel Corp., Cincinnati, OH), 2.6% morpholine and the balance water. The polyethylene-candelilla wax coating (B, Table 2) contained 12.3% polyethylene wax (AC316, Allied Signal), 8.8% candelilla wax (No. 75, Strahl and Pitsch Inc., W. Babylon, NY), 3.8% oleic acid, 1.1% myristic acid (Emery 655, Henkel Corp.), 1.1% NH_3 and the balance water. The wax-shellac coating (E, Table 2) contained 10% polyethylene wax (AC673, Allied Signal), 5% candelilla wax, 6.7% shellac (R52, Mantrose Haeuser, Attleboro, MA), 2.0% oleic acid, 0.5% myristic acid, 1.0% NH_3 and the balance water. The coatings applied in the packinghouses (for treatment H) were FMC4285, FMC4210 and FMC410, coatings of unknown composition from FMC Corp. (Lakeland, FL).

Treated fruit was stored at 21 ± 1 °C, 55 ± 15% RH except for treatment G5, which was stored at 4.8 ± 0.3 °C.

2.2. Analytical methods

Samples for internal O_2 and CO_2 (five fruit per treatment, each experiment) were withdrawn with a syringe (previously flushed with N_2), with the needle inserted through the blossom end into the internal space of fruit submerged in water. The O_2 and CO_2 concentrations were measured with a gas chromatograph (Model 5890, Hewlett–Packard, Avondale, PA) fitted with a CTR-1 column (2 m × 6 mm, Alltech, Deerfield, IL). Samples were applied with a loop injector. Column flow rate was 140 ml min^{-1}. Temperatures were 40 and 120 °C, for the column and thermal conductivity detector, respectively. Peak areas obtained from standard gas mixtures were determined before and after analysis of the samples. Oxygen concentration was calculated from the O_2–Ar peak area after correction for 0.9% Ar in the atmosphere. Fruit with obvious punctures or peel injuries through which gas could freely diffuse were discarded and no measurements included in the reported data. These were detected by inserting $\approx$ 50 ml air into the cavity of the submerged fruit and observing bubbles.

The fruit was sliced in half and juiced with an electric juice maker with rotating head. Two juice samples were taken per treatment, each pooled from five pieces of fruit. Samples for ethanol determination, kept frozen until analyzed, were spiked with 1000 ppm *n*-propanol as internal standard, centrifuged and injected into the gas chromatograph using a FFAP column (Hewlett–Packard) and flame ionization detector. Injector and detector temperatures were both 250 °C. Column flow was 4 ml min^{-1}. Column temperature was 55 °C for injection, increased 3 °C min^{-1} to 70 °C and held at that temperature for 1 min.

Sensory flavor of the juice was evaluated by 14 panelists after 7 days storage of the fruit, using pooled juice from ten to 15 fruit. Panelists received, along with five juice samples (treatments B, E, F, G and G5) some 'fresh' juice from fruit not coated and stored for 7 days at 5 °C and also 'fermented' juice (fruit with coating G stored at 30 °C for 4–7 days). The samples were graded 0–15 according to distance along 15-cm lines that were labeled 'fermented, over ripe' on the 0 cm end and 'very fresh or very good' on 15 cm end.

Fruit gloss was evaluated visually. Five fruit from each treatment were placed on a tray and the trays were arranged by ten untrained panelists from greatest to least gloss. Oxygen permeability of coatings was measured at 30 °C (with a modified Oxtran 100 from Mocon, Minneapolis, MN) as previously described (Hagenmaier and Shaw, 1992).

2.3. Statistics

Statistix 5 (Analytical Software, Tallahassee, FL) was used for computation of statistical parameters. Best subset and step-wise linear regression methods were used to identify independent variables that were significant ($P < 0.05$). Goodness-of-fit was determined by values of adjusted R^2. Pooled S.E. is shown as error bars on the graphs except when covered by the symbols. The changes in weight and gloss that occurred during storage were computed as changes on numbered fruit and treated as paired comparisons. The reported probabilities (P) are for the null hypotheses. Means were compared at $P < 0.05$ with the LSD statistic.

3. Results and discussion

3.1. Flavor and oxygen permeability

The flavor of the juice from fruit stored at 21 °C was perceived as less 'fresh' (more 'fermented') for treatments F and G, where low-permeability coatings were used, than for treatments B and E, where coating permeability was higher (Tables 2 and 3). On the other hand, treatment G5, which was stored at 5 °C, was rated most fresh even though the least permeable coating was used. It would be expected that fruit with higher-permeability coatings stored at 5 °C would also be rated highly by the panel. Moreover, the sensory score of the juice from fruit stored for 7 days at 5 °C was virtually the same for all varieties, which seems remarkable considering the large ranges in values of internal CO_2 (2.3–20.3%), internal O_2 (0.2–18%) and ethanol (61–974 ppm) for the different varieties (data from Tables 3–5). Although flavor of tangerines was not markedly affected at 5 °C storage for 7 days, the flavor life during longer-term storage cannot be assumed to be unaffected when low-permeability coatings are used.

Flavor stability, similar to internal gases and ethanol, varied for different varieties and even more so for the same variety at different harvest dates (Tables 1, 3–6). Nevertheless, analysis of the data does show some trends. Regression of flavor on coating permeability gave the following equation:

$$\text{Flavor (7 days, 21 °C)} = (9.0 \pm 0.3) - (2.5 \pm 0.4) \times 10^{-16} \times \text{permeability}^{-1}, \quad (1)$$

Table 3
Sensory flavor score of juice after storage of fruit for 7 days[a]

	G5	B	E	F	G
Fg2	11.7[a]	10.0[a]	7.4[b]	10.0[a]	5.9[b]
Fg6	10.9[a]	5.7[bc]	7.4[b]	1.1[d]	4.5[c]
Rb5	12.2[a]	8.4[b]	9.3[b]	6.8[b]	3.5[c]
Sb2	10.3[a]	3.1[b]	10.7[a]	4.8[b]	8.8[a]
Sb4	8.9[ab]	8.1[ab]	10.1[a]	6.6[b]	6.3[b]
Sb9	11.9[a]	9.5[b]	7.1[c]	7.0[c]	3.7[d]
Dn8	9.9[a]	11.3[a]	8.8[ab]	7.0[bc]	5.4[c]
Mr4	10.7[a]	9.8[a]	10.7[a]	6.6[b]	3.1[c]
Mr6	12.3[a]	12.2[a]	8.0[b]	4.8[c]	5.7[c]
Nv2	11.9[a]	8.7[b]	8.8[b]	6.7[b]	6.8[b]
Nv4	11.5[a]	11.0[ab]	8.5[b]	4.9[c]	4.3[c]
Or3	11.5[a]	10.2[a]	6.3[b]	6.8[b]	5.3[b]
Or6	10.5[a]	9.9[a]	9.8[a]	5.8[b]	5.5[b]
Tm6	10.7[a]	8.3[ab]	10.0[a]	6.6[b]	3.9[c]
Tm8	11.4[a]	11.2[a]	10.4[a]	5.8[b]	6.6[b]
Mean	11.1[a]	9.2[b]	8.9[b]	6.1[c]	5.3[c]

[a] Values in a row with the same letter in the superscript are not different ($P < 0.05$).

Table 4
Mean internal CO_2 concentrations of fruit after 7 days storage[a]

	Internal CO_2 values (%, mean)[a]								
	G5	A	B	C	D	E	F	G	H[c]
Fg2	6.0	1.7	5.9	No data	8.4	9.0	11.2	12.3	8.6
Fg6	3.6	2.6	6.8	No data	8.4	7.7	15.9	15.3	4.5
Rb5	6.1	4.4	8.5	No data	7.9	7.8	11.1	13.7	6.7
Sb2	7.0	2.7	6.0	No data	6.8	7.8	9.0	10.3	5.9
Sb4	5.5	4.1	5.8	4.9	8.2	7.6	11.4	11.2	5.5
Sb9	7.5	3.9	8.6	4.1	13.5	15.3	34.9	31.9	8.6
Dn8	2.3	1.4	7.0	5.8	10.0	12.9	18.6	21.9	6.7
Mr4	10.7	3.8	5.4	5.2	8.9	9.6	13.8	22.6	8.0
Mr6	20.3	6.8	6.7	9.0	11.8	15.8	42.6	46.0	8.0
Nv2	3.4	4.2	4.6	7.5	5.3	5.3	5.3	5.5	10.2
Nv4	5.5	4.2	5.2	5.8	9.2	11.4	20.7	20.9	31.1
Or3	7.2	2.6	5.6	5.8	7.8	13.9	27.4	29.6	3.4
Or6	7.5	2.4	5.8	5.4	9.1	8.1	25.2	24.3	10.5
Tm6	6.8	3.0	3.1	4.5	6.9	8.8	12.7	16.0	13.0
Tm8	12.9	4.5	4.9	4.8	8.1	11.4	34.5	36.4	6.1
Mean[b]	7.5[ab]	3.5[a]	6.0[ab]	5.7[ab]	8.7[b]	10.2[b]	19.6[c]	21.2[c]	

[a] $n = 5$; S.E. = 10% of mean.
[b] Overall means with same superscript are not different ($P < 0.05$).
[c] The overall mean 'H' is not meaningful because the coating varied (see Table 1).

with adjusted $R^2 = 0.44$, $F = 48$ and $P < 0.001$. Note that permeability of a film or coating is defined as permeability × thickness. For coatings of approximately equal thickness, such as these were (≈ 4 μm), the difference in gas concentration across a permeable film or coating is proportional to 1/permeability, which is the reason why permeability^{-1} was used in Eq. (1) (Crank, 1964). No improvement in goodness-of-fit was achieved by including values of acidity or Brix as other independent variables. Eq. (1) predicted values of flavor of 8.9 ± 1.9 for coating B and 4.9 ± 1.9 for G, the coatings with highest and lowest permeability, respectively, for fruit stored for 7 days at 21 °C.

Flavor life of tangerines and tangelos decreased markedly at 21 °C with the low-permeability coatings, especially for those trials when ethanol was > 1500 ppm (Tables 2, 3 and 6). For the nine experiments with at least one trial having > 1500 ppm ethanol, $R^2 = 0.71$ and $P < 0.0001$. For the six experiments where 7 day storage was not sufficient time for any sample to have 1500 ppm ethanol, $R^2 = 0.06$ and $P > 0.05$, which indicates that the panel was only able to detect flavor changes when ethanol was approximately > 1500 ppm.

Thus, oxygen permeability of the coating would be useful in predicting the effect of storage on flavor and for this reason, knowledge of oxygen permeability would seem to be of much benefit to users of fruit coatings. However, data on oxygen permeabilities of coatings are not generally available and therefore, other properties related to flavor changes were measured.

3.2. Flavor and internal gases

Internal gas concentrations generally reach steady state values less than 1 day after application of the coating and change little for fruit stored at constant temperature, unless the fruit decays (Hasegawa and Iba, 1980). Thus, internal gases measured more than 1 day after application of coatings are sometimes used to estimate the affect of a coating on fruit quality. For our experiments with specialty fruit, the regression of flavor on internal CO_2 gave the following equation (Tables 3 and 4).

Flavor (7 days, 21 °C)

$$= 9.1 \pm 0.5 - (0.12 \pm 0.03) \times [\%\ CO_2]. \quad (2)$$

For this equation $R^2 = 0.25$, $F = 21$ and $P < 0.001$, $n = 60$. No improvement in fit was achieved by including measurements of internal O_2 concentrations. Thus, measurement of internal gas concentrations would not have been as useful for prediction of flavor changes as knowledge of oxygen permeability of the coating.

Now consider the usefulness of knowing both coating permeability and internal gas concentrations. The regression equation for flavor was as follows.

Flavor (7 days, 21 °C)

$$= 9.4 \pm 0.4 - (2.0 \pm 0.2) \times 10^{-16} \times \text{permeability}^{-1} - (0.044 \pm 0.029) \times [\%\ CO_2], \quad (3)$$

with $R^2 = 0.45$, $F = 26$, $P < 0.001$, which offers little improvement to either variable by itself. A comparison of Eq. (1) and Eq. (3) shows that the ability to predict flavor after storage was about the same with permeability alone as it was with permeability and internal CO_2. This suggests that variance in the measurement of flavor may have been too high for accurate prediction. As an alternate to sensory measurement of flavor, one might consider how ethanol changed during storage.

3.3. Ethanol

In general, it is well known that flavor acceptability of citrus juice decreases at high ethanol concentrations (Ahmad and Khan, 1987). Regression of flavor on ethanol gave the following equation

Flavor (7 days, 21 °C)

$$= 8.7 \pm 0.4 - (0.0009 \pm 0.0002) \times [\text{EtOH}], \quad (4)$$

where [EtOH] is the ethanol concentration of the juice in units of ppm. For the equation $R^2 = 0.21$, $F = 17$ and $P < 0.001$, $n = 60$. The samples with highest ethanol tended to coincide with those having highest internal CO_2 and these had low flavor scores (Tables 3, 4 and 6). The mean flavor score was 5.9 (S.D. = 1.6) for the 20 samples with highest ethanol (range 1558–4744 ppm), all of

Table 5
Mean internal O_2 concentrations of fruit after 7 days storage[a]

	Internal O_2 (%, mean)								
	G5	A	B	C	D	E	F	G	H
Fg2	12.9	18.5	12.7	No data	5.4	4.9	3.7	3.8	10.7
Fg6	14.9	16.9	10.5	No data	6.9	8.3	0.9	2.6	14.9
Rb5	11.8	14.6	7.1	No data	7.9	8.7	6.7	3.0	10.7
Sb2	5.4	16.1	10.5	No data	9.9	8.1	8.0	5.2	10.3
Sb4	10.5	13.1	11.6	11.5	7.6	7.6	5.1	6.2	10.9
Sb9	1.9	14.3	3.4	4.1	0.8	2.9	1.1	0.3	3.3
Dn8	17.7	16.0	10.4	7.0	5.4	3.6	1.0	3.6	9.7
Mr4	5.1	14.6	10.9	6.6	3.3	2.7	2.5	1.9	2.3
Mr6	0.2	12.5	8.9	1.9	2.2	0.8	0.7	−0.1	8.0
Nv2	13.4	14.1	12.7	7.9	13.0	12.9	14.1	13.3	6.1
Nv4	5.9	13.8	9.1	3.5	5.3	3.7	3.9	2.1	1.3
Or3	7.9	17.2	12.9	10.4	10.8	1.6	3.6	3.4	16.5
Or6	1.9	17.0	10.4	9.1	7.7	8.8	1.6	0.6	16.0
Tm6	3.4	15.8	15.5	8.4	5.1	3.7	2.5	0.5	0.5
Tm8	1.5	15.4	8.9	6.2	3.7	0.3	0.0	0.4	8.2
Mean[b]	7.6[c]	15.3[a]	10.4[b]	7.0[c]	6.3[c]	5.2[cd]	3.7[d]	3.1[d]	

[a] $n = 5$; pooled S.E. = 1.3% O_2.
[b] Overall means with the same superscript are not different ($P < 0.05$).

Table 6
Ethanol concentrations (ppm) in juice[a]

	Z	G5	A	B	C	D	E	F	G	H
Fg2	55	61	91	233	No data	739	555	567	1033	265
Fg6	166	192	297	417	No data	842	599	1265	773	359
Rb5	109	135	147	390	No data	570	435	967	1338	409
Sb2	152	203	120	260	No data	305	273	635	794	305
Sb4	71	141	186	205	327	544	493	682	887	333
Sb9	124	384	219	1269	1416	1623	2490	4531	4459	1399
Dn8	65	974	101	160	531	1292	1045	1988	2354	549
Mr4	124	448	153	413	543	997	1216	1257	3154	1113
Mr6	154	962	207	750	1523	1965	2508	4744	4307	1192
Nv2	173	237	141	147	371	198	192	333	442	697
Nv4	38	84	45	320	797	1415	1335	2129	2791	3021
Or3	199	282	256	519	755	1066	2234	2381	2087	512
Or6	160	672	207	826	1261	1767	1088	3021	3289	1210
Tm6	94	183	65	172	342	643	667	673	1558	1180
Tm8	77	449	95	431	590	1068	2083	2529	3023	638
Mean[b]	117[a]	360[ab]	155[a]	434[ab]	769[bc]	1002[c]	1148[c]	1847[d]	2153[d]	

[a] $n = 2$, pooled S.E. = 14% of value.
[b] Overall means with same superscript are not different ($P < 0.05$).

which were stored at 21 °C. The 20 samples with highest internal CO_2 (range: 15.3–46%) at 21 °C had mean flavor score of 5.3 (S.D. = 1.6). Thus, it would seem useful to consider how ethanol content depended on internal gas concentrations.

The regression equation for data from all varieties and experiments (Tables 4 and 6) was:

$$\text{EtOH (ppm after 7 days at 21 °C)} = -(95 \pm 64) + (108 \pm 5) \times [\%\ CO_2]. \quad (5)$$

For this equation $R^2 = 0.82$, $F = 543$ and $P < 0.001$, $n = 116$. Ethanol values calculated from Eq. (5) were 283 ± 434 and 2298 ± 435 ppm, respectively, for 3.5 and 21.2% CO_2, the mean values for treatments A and G. Thus, the equation is useful for prediction of high values of ethanol, but not low values. Only a slight improvement in goodness-of-fit (to $R^2 = 0.85$) was achieved by including internal O_2 as a variable. No improvement in fit was achieved with inclusion of data for permeability, although ethanol was significantly correlated with O_2 resistance ($R^2 = 0.25$, $P < 0.001$). Inclusion of Brix or acid did not improve fit. Regression equations similar to Eq. (5) were calculated for the individual varieties and the slopes decreased in the order Sunburst, Nova, Murcott, Dancy, Orlando, Temple, Robinson and Fallglo, suggesting a decreased dependence of ethanol on internal CO_2 in that order.

Ethanol content of stored, coated fruit was independent of ethanol content of the non-coated fruit on day zero. Initial ethanol contents (Table 6, column Z) were only useful for predicting the ethanol content of non-coated fruit after storage (column A). The mean increase in ethanol for non-coated fruit during storage for 7 days was only 38 ± 13 ppm. Therefore, the ethanol content before application of the coating seems not to be useful information.

Fruit samples from treatments A, C, D and H were not presented to the panel for flavor evaluation, but their values of permeability, ethanol and internal gases make it possible to make estimates of their affect on flavor (Tables 2, 4–6). The non-coated fruit (treatment A), had lowest internal CO_2, highest O_2 values and little increase in ethanol, suggesting good flavor after 7 days at 21 °C storage. The polyethylene wax coating (treatment C) had similar internal gases and ethanol to the polyethylene-candelilla wax coating (B) and therefore, similar flavor would also be expected. The carnauba-shellac coating (D) would

be expected to have similar flavor to the experimental candelilla-shellac coating (E) for the same reason.

3.4. Internal gas extinction point

The ethanol content of fruit stored for 7 days at 21 °C was >2000 ppm only when the mean internal O_2 was $<4\%$ (Tables 5 and 6, Fig. 1). Fruit with such low internal O_2 seems to have suffered a fate similar to fruit and vegetables stored in controlled atmospheres with environmental O_2 below the so-called 'extinction point', that is, anaerobiosis (Ko et al., 1996). Thus, our data suggests that $\approx 4\%$ internal O_2 at 21 °C might be considered an 'internal-gas extinction point' for mandarin hybrids.

3.5. Fruit coated in packinghouses

It is of interest to compare the fruit coated in our laboratory with fruit coated in packinghouses (treatment H), for which the ethanol range was 305–3021 ppm (Table 6) and the internal CO_2 range 3.4–31.1% (Table 4). These wide ranges reflect the fact that different waxes were applied at the packinghouses (Table 1). The ethanol and internal CO_2 of packinghouse-coated fruit with FMC coating 410 (experiments Sb4, Sb9, Mr4, Nv4, Or6 and Tm6) were relatively high and similar to those of coatings with low permeability (E, F and G). In contrast, the packinghouse-coated fruit with FMC 4285 coating had low CO_2 and ethanol similar to treatment B. Sunburst tangerines and tangelos purchased December 22 from Florida supermarkets had mean internal CO_2 of 12.4 and 9.8%, respectively, somewhat lower than late-season Sunburst and tangelos with treatments F and G coated in our laboratory (Table 4).

3.6. Gloss

Gloss scores for F, G, D, C, B, E and A were 7.5^a, 6.9^b, 5.1^c, 4.3^d, 4.0^d, 3.2^e and 1.0^f, respectively. Values with the same superscript are not different ($P<0.05$). Thus, the resin-based coatings (treatments F and G) had relatively higher gloss than the wax-based coatings in our studies,

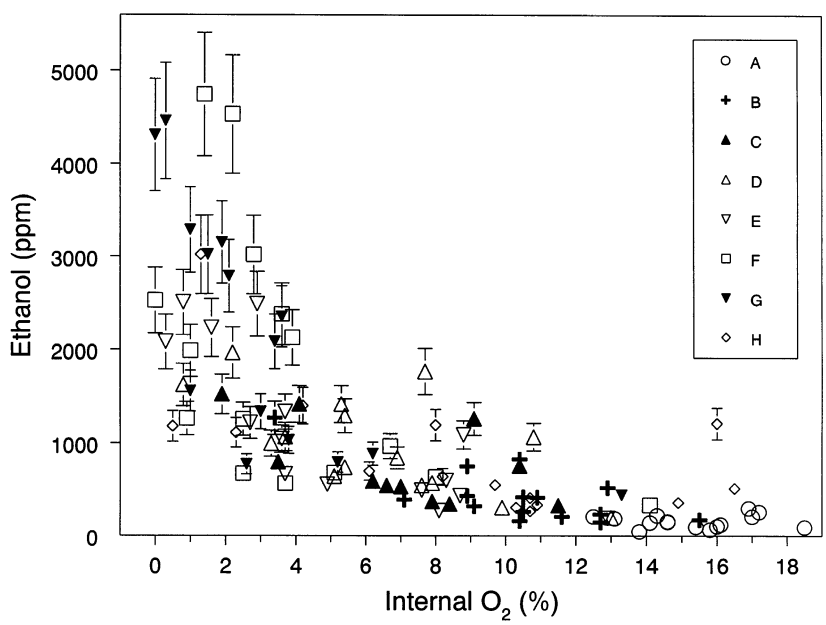

Fig. 1. Ethanol of pooled juice versus mean internal O_2. The fruit ($n=5$) were stored for 7 days at 21 °C. The symbols represent the different coating treatments (Table 2).

which is generally well known. But the resin-based coatings also gave the most off-flavor and therefore, selection of a coating is a trade-off between flavor and appearance.

4. Conclusion

Flavor of tangerines stored for 7 days at 21 °C was rated markedly less fresh with coatings having oxygen permeability $\leq 1.1 \times 10^{-16}$ mol m s^{-1} Pa^{-1}, mean internal CO_2 $> 14\%$, mean internal O_2 $< 4\%$ and juice ethanol > 1500 ppm. Oxygen permeabilities of coatings seem to be useful for predicting flavor changes. Coatings made without resin or shellac (treatments B and C) were suitable for all fruit. Those containing resin or shellac tended to have low O_2 permeability and tended to adversely affect fruit flavor. All coatings seemed suitable for storage of specialty citrus fruit for 7 days at 5 °C.

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