Managing Postharvest Storage Issues in 'Shiranui' Mandarin

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Abstract. 'Shiranui' is a mandarin (*Citrus reticulata* var. *austera*) that is highly treasured for its unique and delicious flavor, and obtains premium prices in the marketplace. Although flavorful, 'Shiranui' tends to develop off-flavor during storage. In this study we examined the use of different storage wax (SW) and pack wax (PW) combinations to determine whether flavor in 'Shiranui' can be improved after storage by adjusting wax coating protocols. In the initial test, either SW or no wax was applied after harvest, and each was followed by an application of SW or one of two types of PW after 1 day, 3 weeks, or 7 weeks of storage and then held 1 week at either 7 or 20 °C. Results indicate that the initial wax was not an important factor but the use of SW instead of either type of PW as the final coating led to greater internal oxygen levels in the fruit and less off-flavor formation. The lessening of off-flavor by SW was significant only after 20 °C of storage, when off-flavor was greatest. Greater weight loss accompanied the use of SW as the final coating. In a second test, SW with greater solids concentrations (5%, 10%, and 15%) were evaluated to attempt to reduce weight loss, but this led to greater development of off-flavor and loss in acceptability than observed when using SW with 1% solids in test 1. 'Shiranui' is prone to developing off-flavor in storage, but this may be mitigated, at least in part, by using SW as the final wax rather than PW.

'Shiranui' mandarin (*Citrus reticulata* var. *austera*), also known as 'Dekopon' in Japan, 'Hallabong' in South Korea, and various commercial names in the United States and Brazil, is renowned and well loved for its large size and rich flavor. A high degree of sweetness (University of California, Riverside 2022) and the composition of flavor volatiles (Umano et al. 2002) are believed to be responsible for the characteristic flavor. It is also quite unique in appearance, with a rough surface and a large, protruding neck on top. The variety has a relatively recent history, having been developed by Japanese government agricultural researchers in 1972 from a cross of 'Kiyomi' tangor (*Citrus* × *aurantium*) and 'Ponkan' (*C. reticulata* var. *austera* Swingle) (Matsumoto 2001). Initially, it was thought by researchers not to have suitable characteristics for commercialization because of its appearance and relatively high acidity, but techniques were developed over time to grow and handle the variety successfully that allowed its positive characteristics to be recognized and highly prized. To prevent confusion stemming from the diversity of names, the variety will be referred to as Shiranui throughout.

There are several challenges in the postharvest handling of 'Shiranui', one of the foremost being the common need to reduce the acidity of the fruit before allowing the fruit to be marketed. This is accomplished in Japan by holding the fruit in cool ambient conditions for 20 to 40 d to allow the acidity to drop to acceptable levels (University of California, Riverside 2022), whereas in the United States the fruit are held for variable amounts of time at 20 °C after harvest to reduce acidity to less than 1.3%. Associated with this is the greater risk of decay from holding the fruit at higher temperatures than the preferred storage temperature for mandarins [5 to 8 °C (Arpaia and Kader 2000)] that would be most effective at reducing acidity. A variety of interventions have been tested to maintain postharvest quality of 'Shiranui', including moisture permeable sheets (Masamoto et al. 2007), preharvest calcium chloride application (Vasconcelos et al. 2020b), and ultraviolet radiation with and without modified atmosphere (Vasconcelos et al. 2020a) with varying degrees of success.

Food safety and decay concerns necessitate that citrus (*Citrus* sp.) be washed before packing to minimize any potential microbial contamination on the fruit that is present before marketing (Gomba et al. 2017). In a commercial situation, this also serves to prepare fruit for wax application and is accomplished by processing on a packing line where the fruit are washed and sanitized with a variety of solutions, and passed over rollers and brushes (Miller et al. 2006). Loss of epicuticular wax can be a consequence of this processing and is part of the reason that a commercial wax is usually applied as part of the final process to help minimize weight loss. The wax also serves the function of enhancing appearance, but is sometimes a carrier for fungicides. A common practice with mandarins that are to be stored before final packing is to apply a wax designed specifically for storage [storage wax (SW)] that helps reduce water loss of the fruit yet can be readily removed

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
25.4	inch(es)	mm	0.0394
4.4482	lbf	N	0.2248
1.6093	mile(s)	km	0.6214
1	ppm	$mg \cdot L^{-1}$	1
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

before the application of a pack wax (PW), also known as shipping wax, as the final coating used for shipping and marketing of the fruit (Obenland and Arpaia 2018). PW generally has a good shine and is not meant to be removed easily. Although citrus coatings are beneficial to the maintenance of postharvest quality, there is a danger that the coatings will also restrict fruit gas exchange, leading to the formation of off-flavors (Marcilla et al. 2009; Obenland et al. 2013; Porat et al. 2005; Tietel et al. 2010; Ummarat et al. 2015). It is believed that the dense nature of their peels makes mandarins more susceptible to this problem than other types of citruses (Shi et al. 2007). ‘Shiranui’ appears to be quite sensitive to this disorder (A. Lombardi, personal communication), perhaps because of the presence of a peel that is much thicker than the average mandarin.

The purpose of our research was to evaluate the use of different coating protocols and storage temperatures suitable for ‘Shiranui’ mandarins in a commercial packing house. The research was the result of the recognition that special procedures would be needed for this highly valuable but more-difficult-to-handle mandarin variety.

Materials and methods

Fruit

Before experimentation, three separately handled grower lots of ‘Shiranui’ mandarins harvested the previous day had been treated initially in a commercial packing house located in Traver, CA, USA. The fruit were floated into a tank of 3% to 3.5% sodium bicarbonate followed by a hot imazalil (IMZ) fungicide drench (350 mg·L^{-1}). They were then run through the waxer, graded, sized (peak size distribution among the three grower lots were used), and sorted. A short-term degreening wax with 1% solids (PacRite 505-15; Pace International, Wapato, WA, USA), including 2000 mg·L^{-1} IMZ, was used as the SW, with some of the fruit not receiving any coating (Fig. 1). The primary ingredients in this coating are nonylphenol polyethylene glycol ether along with other proprietary materials. Throughout this article the applied coatings are referred to as wax because this term has been historically used in the US citrus industry. After preparation by the packing house, the fruit were transported the same day to the University of California Kearney Agricultural Center (UCKAC) in Parlier, CA, USA, ∼15 miles from Traver. The fruit were placed into 7 °C storage with 90% relative humidity (RH) upon receipt. For test 2, the storage protocols were identical to those described earlier and used an additional three ‘Shiranui’ grower lots.

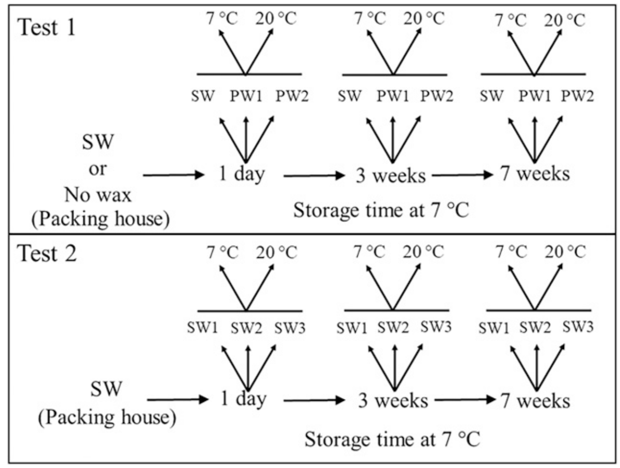

Fig. 1. Schematic showing experimental setup for both test 1 and test 2 using ‘Shiranui’ mandarins. PW1 = pack wax 1; PW2 = pack wax 2; SW = storage wax (1% solids); SW1, SW2, and SW3 = storage wax with solids concentrations of 5%, 10%, and 15%, respectively. (°C × 1.8) + 32 = °F.

Wax application and storage

Test 1. The experimental procedure detailing the wax application and storage protocols is shown in Fig. 1 (test 1). A portion of the fruit (1 d of storage) that had been obtained the previous day at the packing house in Traver was transported to the University of California Lindcove Research and Extension Center (LREC) near Woodlake, CA, USA, at ambient temperature in a covered vehicle. The fruit were cleaned on a research-scale packing line at LREC, using a hot (43 °C) drench containing 250 mg·L^{-1} IMZ (Freshgard 75 WSG; John Bean Technologies Corp., Lakeland, FL, USA). The fruit were then waxed with either SW or either one of the two PWs. PW1 was Natural Shine 965 EU (Pace International, Wapato, WA, USA) and PW2 was Primafresh 680EU (Pace International). Both PWs were carnauba based. PW2 is not commonly used for citrus, but was selected for its favorable gas exchange properties. All waxes included an additional 2000 mg·L^{-1} IMZ. The wax was applied by air-assisted nozzles as the fruit moved over brushes, followed by passage through a 43 °C drying tunnel. After wax application, the fruit were transported back to UCKAC and held for an additional week at either 7 °C (85% to 95% RH) or 20 °C (75% RH). The storage at 20 °C was to simulate typical retail and home use.

The remaining fruit at UCKAC that were not used for the 1-week evaluation were stored at 7 °C (85% to 90% RH) for either 3 or 7 weeks. At the end of each storage duration, a subsample of fruit was evaluated for decay and all decayed fruit were removed. The following day, this subsample was transported to LREC and treated as described earlier. Upon return to the UCKAC, the fruit were held either at 7 or 20 °C for an additional 1 week.

Test 2. Based on the results from test 1, further testing was designed to examine the effect of using SW at different levels of solids instead of a final PW (Fig. 1, test 2). The timing and methodology of treatment at LREC were the same as those in test 1, except that the coatings applied were SW adjusted to have levels of solids of 5% (SW1), 10% (SW2), or 15% (SW3). Conditions of storage at LREC were the same as described for test 1.

Fruit quality evaluation

Twenty fruits for each treatment per evaluation time for each grower lot were rated on a 0- to 5-point scale for overall visual appearance. Decay incidence of all fruit was noted both before the application of waxes at LREC and at the time of final evaluation in both tests. At the beginning of each test, 10 individual fruit per treatment per evaluation time for each grower were preweighed and, at the

Table 1. Quality of 'Shiranui' mandarins as influenced by wax application protocol and final storage temperature after 1, 4, or 8 weeks of total storage in test 1.

Total storage[i]	Wax applications (initial[ii]/final[iii])	Wt loss (%)	Firmness[iv] (N)	SSC[v] (%)	TA[vi] (%)	SSC/TA
1 Week						
7 °C	SW/SW	2.44 a[vii]	14.38 c	15.15 a	1.00 a	15.59 a
	SW/PW1	1.79 bc	16.51 a	15.03 a	1.00 a	15.16 a
	SW/PW2	1.83 b	14.63 bc	15.08 a	1.01 a	15.21 a
	NW/PW1	1.71 bc	15.60 ab	14.87 a	1.05 a	14.38 a
	NW/PW2	1.63 c	16.04 a	14.92 a	1.01 a	15.02 a
	$P > F$	<0.0001	0.0007	0.7894	0.5500	0.1021
20 °C	SW/SW	3.02 a	13.55 c	15.36 a	0.96 a	16.27 a
	SW/PW1	2.10 bc	16.37 a	15.23 ab	1.01 a	15.27 a
	SW/PW2	2.19 b	15.24 b	14.83 b	0.99 a	15.36 a
	NW/PW1	2.00 c	15.20 b	14.75 b	0.97 a	15.41 a
	NW/PW2	2.11 bc	15.44 ab	14.73 b	0.95 a	15.74 a
	$P > F$	<0.0001	<0.0001	0.0176	0.3247	0.2350
4 Weeks						
7 °C	SW/SW	7.63 a	10.26 b	15.22 a	1.00 a	15.51 ab
	SW/PW1	6.51 b	11.37 a	15.09 a	1.06 a	14.48 b
	SW/PW2	6.69 b	10.68 ab	15.42 a	0.99 a	15.92 a
	NW/PW1	6.25 b	11.31 a	15.75 a	0.98 a	16.36 a
	NW/PW2	6.40 b	10.79 ab	15.66 a	1.04 a	15.31 ab
	$P > F$	0.0247	0.0428	0.0525	0.2078	0.0133
20 °C	SW/SW	8.86 a	10.94 c	15.58 a	1.01 a	15.83 bc
	SW/PW1	7.16 a	12.90 a	15.09 a	1.01 a	15.07 c
	SW/PW2	7.36 a	11.65 bc	15.45 a	0.97 ab	16.17 ab
	NW/PW1	6.96 a	12.04 b	15.35 a	0.91 b	17.11 a
	NW/PW2	6.81 a	11.60 bc	15.63 a	0.97 ab	16.32 ab
	$P > F$	0.4476	0.0131	0.1379	0.0159	0.0037
8 Weeks						
7 °C	SW/SW	13.93 a	8.67 a	16.14 a	0.87 c	18.92 a
	SW/PW1	11.61 b	9.17 a	16.17 a	0.92 ab	17.86 bc
	SW/PW2	11.55 b	9.49 a	16.17 a	1.00 a	16.38 d
	NW/PW1	11.88 b	9.09 a	16.29 a	0.98 ab	16.87 cd
	NW/PW2	12.66 ab	9.11 a	16.42 a	0.89 c	18.75 ab
	$P > F$	0.0093	0.2139	0.9036	0.0002	<0.0001
20 °C	SW/SW	14.96 a	8.79 b	16.55 a	0.88 a	19.14 a
	SW/PW1	12.77 a	10.10 a	15.90 a	0.89 a	18.05 a
	SW/PW2	13.01 a	9.31 ab	15.89 a	0.85 a	19.09 a
	NW/PW1	12.81 a	8.62 b	15.72 a	0.84 a	19.08 a
	NW/PW2	13.31 a	9.88 a	16.05 a	0.86 a	19.04 a
	$P > F$	0.2598	<0.0001	0.0709	0.4761	0.3449

[i] Temperature of final week of storage; (°C × 1.8) + 32 = °F.
[ii] Storage wax, 1% solids (SW), applied soon after harvest.
[iii] SW, pack wax 1 (PW1), or pack wax 2 (PW2) applied after either 1 d, 3 weeks, or 7 weeks of storage.
[iv] 1 N = 0.2248 lbf.
[v] SSC = soluble solids concentration.
[vi] TA = titratable acidity.
[vii] Different letters indicate statistical significance at $P \leq 0.05$ within storage time and temperature.

designated evaluation time, the individual fruit was reweighed to provide an estimate of weight loss. Weight loss percentage was calculated as the final weight divided by the initial weight multiplied by 100. Firmness was measured on 10 fruit per treatment per evaluation time for each grower lot using a fruit texture analyzer [model GS-15; GÜSS Manufacturing (Pty) Ltd., Strand, South Africa]. The same 10 fruit were juiced using a tabletop juicer (model 932; Hamilton-Beach, WA, NC, USA), and the juice was then passed through a screen and used to determine soluble solids concentration (SSC) and titratable acidity (TA). SSC was measured with a temperature-corrected refractometer (model 10.423; AO Scientific, Buffalo, NY, USA) and TA by titration with 0.1 mol·L^{-1} sodium hydroxide to an endpoint of 8.2 using an automatic titration system (model T50A; Mettler-Toledo, Columbus, OH, USA). TA is expressed as percentage of citric acid.

Fruit internal atmosphere

Five fruit were sampled for every replication by submerging them under water and using a gastight syringe to withdraw 0.5 mL of gas from inside the fruit. The gas samples were then injected into a gas chromatograph (GC-14A; Shimadzu Scientific Instruments, Columbia, MD, USA) fitted with a CTR1 column and a thermal conductivity detector for analysis of internal oxygen concentrations. Helium flow was maintained at 0.83 mL·s^{-1}, and oven and detector temperatures at 50 and 70 °C, respectively.

Sensory evaluation

A 15-fruit sample for each grower lot per treatment was used for sensory evaluation. The fruit were peeled, and segments were separated and combined to form a composite sample for each treatment. Sensory evaluations for 1, 4, and 8 weeks were conducted over a 3-d period, with one grower lot evaluated each day. Employees of the UCKAC were used as sensory evaluation panelists. Because of their extensive experience with the evaluation of mandarins and other citrus, they can be considered semi-experts. Sensory testing was conducted with the panelists seated in individual booths. Serving of the samples was done in 30-mL soufflé cups into which one or two segments were placed that were at room temperature. Numbering of the cups was in random order. To cleanse the palate between samples, water was supplied. For each tasting, 15 to 20 panelists were used. Panelists gave ratings for acceptability, sweetness, tartness, juiciness, and degree of off-flavor present by marking lines on 150-mm lines. The distance from the origin indicated the intensity of each attribute, with a greater number indicating a greater intensity. The scales were anchored at the extremes only, with no markings or words in the middle.

Statistical analysis

Analyses for quality and sensory attributes and internal atmosphere concentrations were conducted using a general linear model in a statistical software program (SAS version 9.4; SAS Institute Inc., Cary, NC, USA), with wax type or wax combination and grower as fixed factors within storage time and final storage temperature. Mean separations were performed using the Waller–Duncan K-ratio test ($P = 0.05$).

Results and discussion

Citrus packed and marketed in the United States is generally washed and sanitized on a commercial packing line for decay control, food safety, and appearance reasons. 'Shiranui' presented a particular challenge in doing this because of a tendency to develop off-flavors during storage that can be exacerbated by both the application of coatings during the packing process and the need to hold the fruit for extended periods after packing to reduce acidity (A. Lombardi, personal communication). Our research examined different coating protocols designed to find a means to process 'Shiranui' mandarins commercially that maintains the sensory quality of this high-value fruit.

In test 1 (Fig. 1), the factors examined were the initial coating applied at the end of the packing process [no wax (NW) or SW]; the wax applied after 1 d, 3 weeks, or 7 weeks of storage (SW, PW1, and PW2); and the temperature during the final week of storage (7 or 20 °C). The different storage times represented different periods when the fruit were stored to reduce acidity or to manage demand for the fruit and the final storage temperatures being alternatives for marketing temperatures.

Quality parameters were evaluated following each of the three storage

Table 2. Response of key sensory attributes to wax application protocol and final storage temperature for 'Shiranui' mandarins after 1, 4, or 8 weeks of total storage in test 1.

Total storage[i]	Wax applications (initial[ii]/final[iii])	Acceptability[iv]	Off-flavor[iv]
1 Week			
7 °C	SW/SW	111.92 a[v]	30.62 a
	SW/PW1	102.40 a	41.93 a
	SW/PW2	104.84 a	37.25 a
	NW/PW1	109.71 a	30.26 a
	NW/PW2	106.55 a	32.11 a
	$P > F$	0.6211	0.4720
20 °C	SW/SW	94.32 a	51.31 c
	SW/PW1	78.67 a	76.50 ab
	SW/PW2	73.28 a	91.18 a
	NW/PW1	82.36 a	75.94 ab
	NW/PW2	80.54 a	65.77 bc
	$P > F$	0.1946	0.0035
4 Weeks			
7 °C	SW/SW	98.18 a	43.20 a
	SW/PW1	92.25 a	42.04 a
	SW/PW2	97.86 a	51.93 a
	NW/PW1	104.54 a	46.32 a
	NW/PW2	102.18 a	45.77 a
	$P > F$	0.4662	0.7853
20 °C	SW/SW	90.21 a	61.71 c
	SW/PW1	67.29 b	89.91 ab
	SW/PW2	61.71 b	100.30 a
	NW/PW1	77.56 ab	81.35 b
	NW/PW2	72.31 b	90.97 ab
	$P > F$	0.0116	0.0003
8 Weeks			
7 °C	SW/SW	98.09 a	41.98 a
	SW/PW1	94.50 a	48.85 a
	SW/PW2	94.47 a	54.63 a
	NW/PW1	96.43 a	53.98 a
	NW/PW2	97.26 a	46.00 a
	$P > F$	0.9820	0.4738
20 °C	SW/SW	83.49 a	62.07 c
	SW/PW1	68.73 a	86.06 ab
	SW/PW2	64.67 a	91.13 a
	NW/PW1	75.27 a	84.34 ab
	NW/PW2	68.76 a	84.05 b
	$P > F$	0.1791	0.0112

[i] Temperature of final week of storage. (°C × 1.8) + 32 = °F.
[ii] Storage wax, 1% solids (SW), applied soon after harvest.
[iii] SW, pack wax 1 (PW1), or pack wax 2 (PW2) applied after either 1 d, 3 weeks, or 7 weeks of storage.
[iv] Sensory attribute rated using 150-mm (5.91-inch) line scales, ranging from low to high. Acceptability refers to overall acceptability.
[v] Different letters indicate statistical significance at $P \leq 0.05$ within storage time and temperature.

times for both marketing temperatures (Table 1). Only those parameters with differences that were statistically significant are shown. Data are separated by temperature, because interactions with temperature were often significant. SW/SW had greater weight loss than the other treatment combinations except for both 4 weeks and 8 weeks with final storage at 20 °C, when there were no significant differences. This difference in weight loss was not a result of the initial coating treatment because SW was not more preventative of weight loss than using NW. This is likely a result of the low percentage of solids SW used by the packing house to lessen the known threat of off-flavor development in the fruit. Applying SW as the final application, however, did increase weight loss relative to PW1 and PW2. PWs, such as the two evaluated here, were designed by the manufacturer to be the final coating applied before the fruit leaves the packing house (Hall and Sorenson 2006) and were both clearly better than SW at preventing weight loss in the final week of storage at 7 °C. SW is designed to retard weight loss while in storage, but also must be easy to remove before the application of PW. Weight loss increased progressively with storage time in all treatments and was significantly greater at 20 °C compared with 7 °C (data not shown). Lower firmness of the SW/SW treatment after 1 week of storage corresponded to increased weight loss with this treatment combination, but the effect became less clear with increasing storage. Firmness decreased with storage time, but temperature was not a significant factor. There were no consistent differences in combination treatments in SSC, TA, or SSC/TA.

Off-flavor was significantly less in the SW/SW treatment combination than the other combinations when the final week of storage was at 20 °C (Table 2). The only exception to this was NW/PW2 at 1 week. In those fruit with a final storage at 7 °C, this difference was not seen. It has been found previously that storage temperature in mandarins is closely tied to off-flavor (Obenland et al. 2011; Tietel et al. 2011). In addition, as also shown in prior work (Obenland et al. 2011), off-flavor worsened with longer storage time, and was particularly notable in comparison of 1 week vs. 4 weeks of storage. Internal oxygen levels within the fruit (Fig. 2) were tied closely to the degree of off-flavor in the fruit and were likely an initiator of the off-flavor response. Both storage and temperature acted to ($P \leq 0.05$) lower oxygen within the fruit significantly. The SW/SW treatment is notable for its maintenance of relatively high oxygen levels within the fruit. Except for 4 weeks at 20 °C, acceptability was not associated significantly with the development of off-flavor. It is not clear whether the greater weight loss and lower firmness in the SW/SW fruit had any role in the lessening of the benefit of reduction of off-flavor.

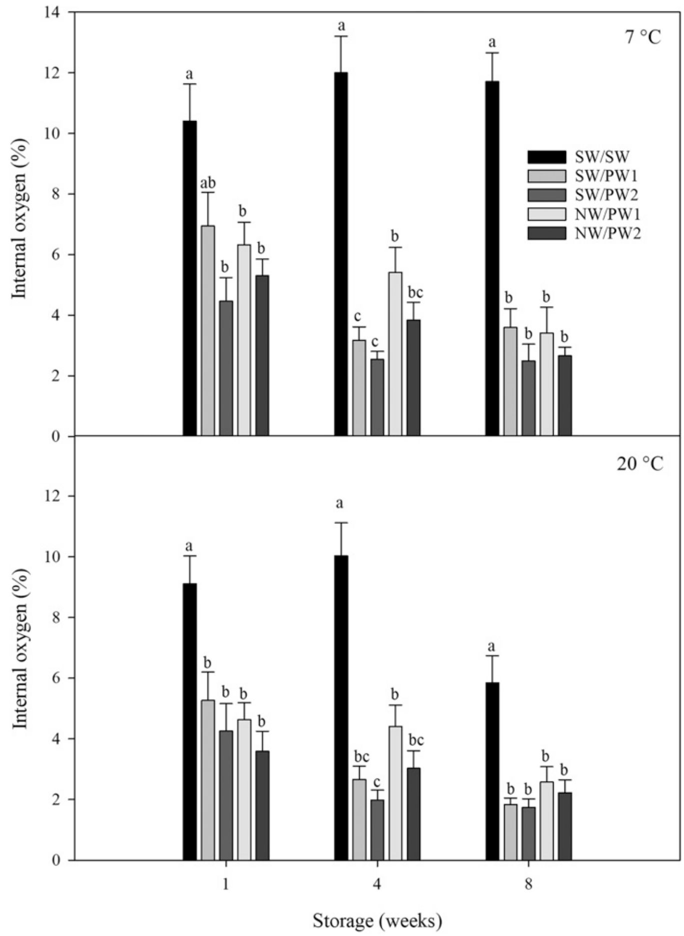

Fig. 2. Internal oxygen concentrations in 'Shiranui' mandarins treated with different wax protocols and final storage temperatures after 1, 4, and 8 weeks of storage in test 1. Wax coatings for each treatment set are shown in the order given. NW = no wax; PW1 = pack wax 1; PW2 = pack wax 2; SW = storage wax. Bars indicate *SE* and different letters indicate statistical significance ($P \leq 0.05$) within a storage temperature and storage time. (°C × 1.8) + 32 = °F.

Given the success of the application of SW as the final coating (SW/SW) in the reduction of off-flavor in 'Shiranui', test 2 was conducted to determine whether SW at greater percentages of solids than the 1% used in test 1 would decrease weight loss without influencing fruit flavor negatively. SW concentrations of 5%, 10%, and 15%, which were applied in the same configuration as test 1, showed no meaningful differences from one another in both quality attributes (data not shown) and sensory properties (Table 3). Even though direct comparisons between tests 1 and 2 should be viewed with caution, because different sets of fruit were used, weight loss was reduced in test 2 by an average of 2.6% relative to test 1 SW/SW values after 8 weeks of storage (data not shown). Examination of the increase in off-flavor in comparing mandarins stored at warm vs. cold temperatures can be used as an estimate of the success of the coating, because higher temperatures can cause a depletion of internal oxygen if gas diffusion is impeded. Using this means of comparison, fruit coated with SW from 5% to 15% solids (Table 3) increased off-flavor to a greater degree (26.5 units) than fruit coated with SW with 1% solids (19.4 units) (Table 2). This also corresponded to statistically

Table 3. Key sensory attribute responses to wax solids concentration of the second storage wax coating and final storage temperature of 'Shiranui' mandarins after 1, 4, or 8 weeks of total storage in test 2.

Total storage[i]	Acceptability[ii]	Off-flavor[ii]
1 Week		
Wax solids	—	—
5%	97.07 a[iii]	55.88 a
10%	98.09 a	48.51 a
15%	90.13 a	56.20 a
P > F	0.2111	0.3405
Temperature	—	—
7 °C	103.05 a	43.81 b
20 °C	87.15 b	63.25 a
P > F	0.0001	0.0001
4 Weeks		
Wax solids	—	—
5%	95.32 a	52.55 a
10%	97.53 a	51.20 a
15%	100.78 a	53.01 a
P > F	0.5797	0.9414
Temperature	—	—
7 °C	107.75 a	35.30 b
20 °C	86.00 b	69.08 a
P > F	<0.0001	<0.0001
8 Weeks		
Wax solids	—	—
5%	91.32 a	56.20 a
10%	91.23 a	59.59 a
15%	94.59 a	52.26 a
P > F	0.7943	0.5408
Temperature	—	—
7 °C	99.37 a	42.93 b
20 °C	85.40 b	69.11 a
P > F	0.0027	<0.0001

[i] Wax compositions applied after either 1, 3, or 7 weeks of storage for total storage times of 1 d, 4 weeks, and 8 weeks, respectively. Temperature of final week of storage. (°C × 1.8) + 32 = °F.
[ii] Sensory attribute rated using 150-mm (5.91-inch) line scales, ranging from low to high. Acceptability refers to overall acceptability.
[iii] Different letters indicate statistical significance at $P \leq 0.05$ within storage time wax solids concentration and temperature.

significant decreases in acceptability in the same fruit (Table 3) and lower internal oxygen levels (data not shown) than those observed for 1% SW in test 1. This indicates that applying SW as a final coating with a solids concentration more than 1% may decrease the observed benefit of off-flavor reduction seen in test 1 and may not be worth the beneficial effect of reduction of weight loss.

Our work indicates that 'Shiranui' mandarin are particularly prone to off-flavor development relative to other mandarins that have been studied in the past. One possible reason for this is the very thick peel that is present in these fruit that may act to reduce gas exchange and promote low oxygen conditions that enhance off-flavor formation. Maintaining 'Shiranui' at a cold temperature (such as 7 °C) during its entire postharvest life would reduce the chance for flavor loss, but may be difficult for retailers and consumers to achieve. Application of a SW with a low percentage of solids, as done in our study, may be another approach. Given the bumpy, uneven nature of the peel, it is also possible that the appearance would not be greatly altered if no wax at all was applied, although greater weight loss will occur. On the other hand, the need to wash and sanitize the fruit to lessen decay and take care of potential food safety issues likely means that some coating needs to be applied.

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