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Effects of Growing Location, Storage Temperature, and Fruit Coating on Postharvest Quality and Quality Retention of 'Sugar Belle'™ Mandarin

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'Sugar Belle'™ mandarin (previously known as LB8-9) was released to Florida citrus growers in 2009. Fruit were evaluated during the 2008–09 and 2009–10 seasons in terms of growing location and response to different postharvest coatings and storage temperatures to further refine their optimum postharvest handling practices. Fruit were obtained from blocks in Orange or Indian River (IR) Counties, washed and coated with either shellac or carnauba wax, and then stored at 1, 4, or 10 °C for up to 39 d and then transferred to ambient temperatures for an additional 7 d. In general, fruit from the Orange County block developed less postharvest decay and peel breakdown than fruit from the IR County block. Uncoated fruit or fruit stored at warmer temperatures developed better external color during storage. Use of coatings, especially carnauba, or storage at cooler temperatures inhibited fruit water loss most. Except for fruit from the IR block during the first season, the development of decay and physiological disorders during storage and subsequent transfer to ambient conditions was inhibited significantly more if stored at 1 or 4 °C than at 10 °C. Fruit from the IR block developed what appeared to be chilling injury (CI) when stored at 1 or 4 °C during the first season only. It is not clear if this different response is due to growing location, age of the block, or some other unknown factor. When CI developed, coating the fruit with either shellac or carnauba wax reduced the development of the symptoms. 'Sugar Belle' mandarins were also found to have a positive, exponential relationship between fruit size and internal seed content.

Fresh citrus is an important industry in Florida with a value of over $430 million during the 2009–10 season (Florida Department of Citrus, 2010).The 'Sugar Belle' mandarin ['Clementine' mandarin (*Citrus reticulata*) × 'Minneola' tangelo, Duncan grapefruit (*C. paradisi*) × Dancy tangerine (*C. reticulata*)] is a new fresh citrus variety developed at the University of Florida and released in late 2009 for commercial production. 'Sugar Belle', previously designated LB8-9, is a mid-season mandarin that matures in Florida between late November and early January and is a promising cultivar for gift fruit shippers during the Christmas holiday season (Dou and Gmitter, 2007). This cultivar has a rich flavor that taste panels have scored approximately equal to 'Sunburst' and 'Murcott' mandarins (Dou et al., 2004; Dou and Gmitter, 2007). As production of this new cultivar increases and markets are developed, it is important to establish optimum postharvest handling practices to assure the fruit arrive at destination markets in top quality.

All fresh citrus shipped from Florida are washed and waxed and citrus coatings commonly used on Florida citrus include both shellac- and carnauba-based formulation. While previous research determined that carnauba coatings maintain 'Sugar Belle' quality best (Dou and Gmitter, 2007), market demands sometime call for the higher gloss appearance from shellac coatings.

Optimum postharvest storage and transit temperatures must also be chosen that are low enough to slow fruit metabolism and senescence-related processes as much as possible, but not so low as to cause physiological disorders such as chilling injury (CI; Ritenour et al., 2009a). Dou and Gmitter (2007) stored 'Sugar Belle' at either 4.4 or 21.1 °C and found that CI developed at 4.4 °C in one of the two seasons evaluated. The current recommended storage temperature for mandarins in Florida is 4.4 °C (Ritenour et al., 2003). Therefore, additional work is needed to more closely establish optimum holding temperatures for 'Sugar Belle' mandarins.

Although previous studies on 'Sugar Belle' have not evaluated the effect of degreening treatments, probably because environmental conditions in November and December usually promote sufficient natural color development, degreening may become necessary if fall temperatures remain warmer than usual (Ritenour et al., 2009b). In addition, we observed that 'Sugar Belles' grown on Florida's East coast did not develop natural color as well as fruit from the middle of the state. Thus, studies are needed to understand degreening effects on 'Sugar Belle' color development and postharvest quality retention.

The objective of the current experiments were to evaluate the

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effects of wax coatings, storage temperatures, and degreening duration on fruit color, decay and disorder development during storage and transfer to simulated retail environments. In addition, the relationship between fruit size and the number of seeds per fruit was also evaluated.

Materials and Methods

'Sugar Belle' fruit were harvested from production blocks in either Orange (central ridge) or Indian River (IR; East coast) County. The groves were managed using commercial cultural practices.

Effects of wax coating and storage temperature on 'Sugar Belle' postharvest quality retention. Fruit were received at the Indian River Research and Education Center (IRREC) postharvest facility on 11 Dec. (IR County) or 12 Dec. (Orange County) in 2008, or on 15 Dec. (IR County) or 16 Dec. (Orange County) in 2009. Fruit were not degreened, but were dipped in 1,000 ppm thiabendazole (TBZ) for 4 min and allowed to sit for 1 h under ambient conditions before washing and waxing on the IRREC research packingline and placing at different storage temperatures. Uncoated fruit were washed and passed over the wax brushes without wax. The experiment was a factorial design evaluating three coating treatments (carnauba, shellac, or uncoated) and three storage temperatures (1, 4, or 10 °C). During storage, the fruit were evaluated biweekly for the development of decay or physiological disorders. After 39 d of cold storage, all fruit were transferred to ambient room conditions (~23 °C) for an additional 14 d to simulate a retail environment before final evaluation. Each treatment consisted of 3 replicates of 40 fruit each.

Effects of degreening duration on 'Sugar Belle' postharvest quality retention. Fruit from the IR County block were harvested on 15 Dec. 2009 and exposed to 5 ppm ethylene, at 29 °C with 90% RH for either 12 or 24 h. Untreated fruit were not exposed to ethylene and kept at ambient conditions. After degreening, fruit were stored at 10 °C and evaluated biweekly for the development of decay and physiological disorders. Each treatment consisted of 3 replicates of 40 fruit each. External peel color was measured on day 0 (before degreening), 1, 7, and 21.

Relationship between 'Sugar Belle' fruit size and internal seed count. Two sets of 'Sugar Belle' fruit samples were received from a commercial packinghouse in IR County on 16 and 23 Dec. 2009, respectively. Each set contained 30 fruit from each of six sizes (80, 100, 120, 150, 180, and 210 fruit per 4/5-bu carton). The diameter of each fruit was measured and the number of seeds within each fruit were counted to determine the relationship between fruit size and seed number.

Fruit quality evaluations. Peel color was measured using a Minolta Chroma Meter (CR-300 series, Minolta Co. Ltd., Japan) at three equidistant locations on each fruit along the equator of the fruit and expressed as L*, a* and b* values. The a*/b*, hue and chroma values were calculated from the a* and b* values. As fruit lose their green color, a*/b* values increase from negative to positive. Hue angle decreases as the peel turns from green (160°) to yellow (90°) to orange (45°). Chroma is a measurement of the color's intensity from near white to characteristic pure color (McGuire, 1992; Voss, 1992).

Fruit weight loss was determined by individually weighing 10 fruit per replicate after transfer to ambient temperatures, and then again 14 d later. Decay and peel disorders were visually evaluated on each fruit biweekly and the percentage of fruit showing any decay or peel breakdown was calculated. Decayed fruits were discarded from the replicate after each evaluation. Evaluations were discontinued after about 50% of the fruits decayed.

Statistical analysis. Percentage data were transformed to arcsine values and all data was analyzed by analysis of variance using SAS (PROC GLM) for PC (SAS Institute Inc., Cary, N.C.). When differences were significant ($P \leq 0.05$), individual treatment means were separated using Duncan's multiple range tests ($P = 0.05$). Means presented are untransformed values.

Results and Discussion

Effects of wax coating and storage temperature on 'Sugar Belle' postharvest quality retention. After harvest and postharvest treatments, 'Sugar Belle' fruit were evaluated for peel color development, weight loss, and the development of decay and peel disorders during cold storage and after an additional 7 d under ambient conditions (simulated retail conditions). While natural fruit color development was commercially acceptable at harvest for the Orange County block, after storage for 39 d, uncoated fruit still developed significantly better color than either of the waxed treatments (Table 1). This is expected, as Grierson and Newhall (1960) reported that color development is greatly inhibited after waxing. Either coating inhibited color development equally. 'Sugar Belle' color was also significantly delayed at cooler storage temperatures, which was also expected based on previous research (Grierson and Newhall, 1960). Fruit from the Orange County block had significantly better color after washing and waxing (a*/b* = 0.97) than fruit from the IR County block (a*/b* = 0.42). Color measurements taken at harvest were not significantly different, but showed the same trend (data not shown).

Wax coatings are applied to fresh citrus to replace the natural water barrier lost when the fruit cuticle is partially removed during washing. Thus, as expected, uncoated fruit lost significantly more weight than either of the wax treatments (Table 2). However, of the waxed fruit, those coated with shellac lost significantly more weight than those coated with carnauba. Dou and Gmitter (2007) also reported that water loss was significantly reduced in 'Sugar Belle' fruit coated with shellac, carnauba, or polyethylene wax, but found no significant differences between the coating formulations. Others have reported greater inhibition of water loss from carnauba than from shellac coated fruit (Brown et al., 1998). However, it is not know when coating supply companies modify their coating formulations. Thus, periodic testing of commercial

Table 1. Peel color of 'Sugar Belle' fruit in 2008 from the Orange County block after 39 d of storage.

Treatment	a*/b*	Hue	Chroma
Coating			
Uncoated	1.22 a[z]	39.85 b	47.09 a
Shellac	1.15 b	41.28 a	46.05 b
Carnauba	1.13 b	41.73 a	44.92 c
Significance	***	***	***
Storage temperature			
1 °C	1.07 c	43.29 a	46.13 a
4 °C	1.11 b	42.08 b	46.43 a
10 °C	1.35 a	36.86 c	45.50 b
Significance	***	***	***
Trt × Temp	***	***	***

[z]Values within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.
[NS, ***]Nonsignificant or significant at $P \leq 0.001$.

Table 2. Weight loss of 'Sugar Belle' fruit in 2008 from the Indian River County block during the first 2 weeks after transfer to ambient temperatures.

Treatment	Wt loss (%)
Coating	
Uncoated	9.85 a[z]
Shellac	7.72 B
Carnauba	6.39 C
Significance	***
Storage temperature	
1 °C	7.76 B
4 °C	8.04 Ab
10 °C	8.26 A
Significance	**
Trt × Temp	*

[z]Values within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.
[*, **, ***]Significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Percentage of 'Sugar Belle' fruit in 2008 from the Orange County block with decay or peel disorders after 39 d of cold storage.

Treatment	Healthy (%)	Diplodia (%)	Green mold (%)	Total decay (%)	Peel breakdown (%)
Coating					
Uncoated	91	5	4	8	1
Shellac	86	6	8	14	0
Carnauba	86	7	7	14	1
Significance	NS	NS	NS	NS	NS
Storage temperature					
1 °C	98 a[z]	1 B	0 b	2 b	1
4 °C	96 a	3 B	0 b	3 b	0
10 °C	68 b	13 A	18 a	31 a	0
Significance	***	***	***	***	NS
Trt × Temp	NS	NS	NS	NS	NS

[z]Values within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.
[NS, ***]Nonsignificant or significant at $P \leq 0.001$.

Table 4. Percentage of 'Sugar Belle' fruit in 2008 from the Orange County block with decay or peel disorders after 39 d of cold storage plus an additional 7 d at room temperature (~23 °C).

Treatment	Healthy (%)	Diplodia (%)	Green mold (%)	Total decay (%)	Peel breakdown (%)
Coating					
Uncoated	60	5	32	38	1
Shellac	51	6	38	45	2
Carnauba	53	5	39	45	1
Significance	NS	NS	NS	NS	NS
Storage temperature					
1 °C	80 a[z]	1 b	16 C	16 c	1
4 °C	61 b	3 b	33 B	33 b	1
10 °C	23 c	13 a	61 A	61 a	2
Significance	***	***	***	***	NS
Trt × Temp	***	***	***	***	NS

[z]Values within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.
[NS, ***]Nonsignificant or significant at $P \leq 0.001$.

coatings is warranted to document potential changes in coating performance. Interestingly, even after the fruit were transferred to ambient temperatures, water loss continued to be slower in fruit previously stored at cooler temperatures.

After cold storage for 39 d, there were between 68% and 98% healthy fruit from the Orange County block, depending on storage temperature (Table 3). Storage at 1 or 4 °C significantly reduced decay due to both diplodia stem-end rot (*Lasiodiplodia theobromae*) and green mold (*Penicillium digitatum*). As long as the temperature is not so low to cause physiological disorders, storage at lower temperatures greatly prolongs shelf life by reducing decay (Ritenour et al., 2003). After transfer to ambient temperatures for 7 d, fruit decay was least (16%) in fruit previously stored at 1 °C, and most (61%) in fruit previously stored at 10 °C (Table 4). Most of the increased decay after transferring to ambient temperatures was due to increased green mold. The effects of storage temperature on postharvest decay on fruit from the 2008 IR block and the 2009 Orange and IR County blocks were similar to the 2008 Orange County block results.

There was very little peel breakdown during cold storage, even after fruit were transferred to ambient conditions for 7 d after cold storage (Tables 3 and 4). Results from both seasons and the IR County block fruit were mostly similar except that in 2008, fruit from the IR block developed significantly more peel breakdown at 4 °C (29%) than at 1 or 10 °C (15% and 10%, respectively). This peel breakdown is likely at least partially related to chilling injury (CI), as the disorder significantly increased after transfer to ambient temperatures to about 42% in fruit previously stored at either 1 or 4 °C, whereas it was 14% in fruit previously stored at 10 °C. It is not clear if this increased susceptibility to peel breakdown in the 2008 IR block is due to location, age of the block, seasonal factors, or some other unknown factor. In 2009, fruit from the IR block did not develop peel breakdown and behaved similar to fruit from the 2008 Orange County block (data not shown). Thus, the optimum storage temperature for 'Sugar Belle' fruit depended on the source of the fruit and the fruit's sensitivity to chilling. Additional work is needed to clarify the cause of differing chilling sensitivity and overall postharvest life between these two blocks.

The choice of fruit coating had no significant effect on postharvest decay in any of the tests (Tables 3 and 4). They also did not usually affect disorders, except for 2008 IR County fruit that developed significantly less peel breakdown (18%) if coated with either carnauba or shellac wax, compared to the uncoated control (60%). Wax coatings are known to inhibit the development of CI in citrus (Brown et al., 1998). However, increased peel breakdown could also be related to increased water loss of the washed, but uncoated fruit compared to the fruit coated with shellac or carnauba wax. However, if the effect was primarily due to water loss, then shellac-coated fruit would have been expected to develop more peel breakdown than those coated with carnauba, because the former lost significantly more water than the latter (Table 2).

Effects of degreening duration. While the fruit from the IR block were already reasonably well colored at the 2009 harvest with an a*/b* ratio of 0.44, degreening for 24 h in 2009 still resulted in significantly better color after 1 or 7 d at 10 °C (Table 5). Significant differences in color disappeared 14 d after degreening (data not shown). Degreening treatments resulted in no significant difference in decay or physiological disorders during subsequent cold storage (data not shown).

Relationship between 'Sugar Belle' fruit size and internal seed count. A clear relationship between fruit size and the number

Table 5. Effect of degreening duration on the development of peel color of 'Sugar Belle' fruit in 2009 from an Indian River County block.

Day after degreening	Duration of degreening (hour)	a*/b*	Hue	Chroma
0	Initial	0.44	66.26	60.16
1	0	0.47 ab[z]	64.99	60.78
	12	0.46 B	65.23	60.15
	24	0.51 A	63.19	59.51
Significance		*	NS	NS
0		0.46 b	65.16 a	67.40
7	12	0.47 b	64.66 a	68.03
	24	0.52 a	62.56 b	67.43
Significance		***	***	NS

[z]Values within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.
[NS, *, ***]Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

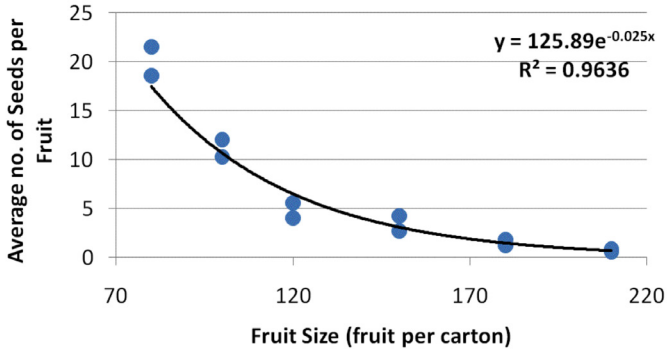

Fig. 1. Relationship between 'Sugar Belle' fruit size and the number of seeds per fruit. Fruit were collected from a commercial packinghouse on two different dates.

of seeds per fruit was established (Fig. 1). The largest fruit (size 80) contained around 20 seeds per fruit, while the smallest fruit (size 210) were almost completely seedless. An exponential trendline gave the best fit to the data, with an R^2 value of 0.96. Previous studies have reported the significant correlation between fruit size and seed number in 'Clementine' mandarin and 'Valencia' orange (Cameron et al., 1960; Soost, 1956).

In conclusion, variability in chilling susceptibility is the most important factor making it difficult to recommend an optimum storage temperature for 'Sugar Belle' fruit. While most fruit will maintain quality best at 1 °C, the potential for some fruit to be chilling susceptible makes it dangerous to recommend temperatures below 10 °C until we can predict when such sensitivity will occur. The reason for this difference in chilling susceptibility is unclear and needs to be evaluated further. Furthermore, while there were no significant differences in postharvest quality retention when either shellac or carnauba coatings were used, carnauba coatings are preferred for use with 'Sugar Belle' because it resulted in significantly better fruit water retention than shellac. Dou and Gmitter (2007) also suggest that carnauba wax is preferred for use with 'Sugar Belle'. Results from one experiment also suggest that this fruit can be degreened at least 24 h to significantly enhance external color development, but with no significantly loss in postharvest quality or shelf life. Finally, the current results show a clear relationship between fruit size and seed content.

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