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Harvest Maturity, Pre-cutting Wash, and Post-processing Dip to Improve Quality of Fresh-cut Carambola Fruit

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'Arkin' carambola (*Averrhoa carambola* L.) fruit harvested at color break or full yellow stage were washed with water or with an alkaline solution (pH 12), cut to 10-mm slices, and dipped in calcium ascorbate (Ca ASA), ascorbic acid (ASA), or water, packaged in perforated clamshells, and stored for up to 14 days storage at 4 °C. Surface color, flesh firmness, soluble solids content (SSC), titratable acidity (TA), and microbial population of the cut slices were determined on days 0, 7, and 14. The alkaline wash reduced microbial loads on the cut slices throughout the entire storage period. ASA and Ca ASA inhibited cut surface browning as indicated by lower a* value, higher L* and hue values, and higher scores in visual quality. Ca ASA-treated carambola also maintained a firm and crisp texture as shown by the high firmness break force. An informal sensory panel preferred slices treated with Ca ASA for reduced sour, astringent, and bitter tastes probably due to the binding of soluble oxalic acid to form insoluble Ca oxalate. But, care must be taken to avoid phytotoxicity caused by the alkaline pre-cutting treatment, and cut surface drying that was enhanced by the Ca ASA application.

Carambola (*Averrhoa carambola* L.) is also known as star fruit as its cross-section resembles a star. Due to its characteristic shape and agreeable sweet-acid flavor, carambola has great potential for use in salads or as a garnish. The first fresh-cut carambola research was conducted by Matthews et al. (1989), and there has been increased interest on quality maintenance of cut carambolas since then (Matthews and Myers, 1995; Teixeira et al., 2005, 2006, 2007; Weller et al., 1995, 1997). One of the most fundamental factors affecting the quality of cut carambola is color change on the cut surface. Surface browning of cut carambola is due to polyphenol oxidase (PPO) mediated oxidation of phenolic compounds (Weller et al., 1995). Weller (1997) reported that PPO activity and phenolic content of cut carambola increased during storage, and that ascorbic acid (ASA) dip inhibited cut surface browning. Teixeira (2008) confirmed the inhibition of PPO in cut carambola by using an ASA dip.

Carambola fruit are usually harvested at the color break or half yellow stage, since when harvested at the full yellow stage fruit are more susceptible to mechanical damage and rib browning (O'Hare, 1993; Paull and Chen, 2004). Carambola may develop a full yellow color during storage but once harvested, sugar content will not change whereas titratable acidity (TA) will decrease (Campbell et al., 1987; Warren et al., 2007). Teixeira et al. (2005) studied the effect of maturity on cut carambola physiology and quality, and found that slices from fruit harvested mature-green (50% yellow) presented better color and appearance, but had poor taste compared to fruit harvested full yellow.

Pre- and post-processing application of a calcium salt solution is commonly used for the maintenance of firmness in fresh-cut fruits (Bai et al., 2009; Toivonen and Brummell, 2008). Although carambola fruit do not present significant softening during postharvest storage (Chin et al., 1999), a preharvest application of Ca-EDTA improved postharvest quality and storability of whole carambola fruit (Kaneta et al., 2006). Teixeira (2008) found that a post-cutting dip in ASA, citric acid, and Ca-EDTA did not affect color, texture, or visual appearance, although there were small changes in the control during 9 d storage at 4 °C. However, ASA dips reduced PPO activity (Teixeira et al., 2008).

Sanitation of whole fruit is also critical for a successful fresh-cut product (Narciso and Plotto, 2005). Narciso et al. (2009) developed a new method to sanitize fruit peel for the fresh and fresh-cut market using an alkaline rinse to dislodge microorganisms that tightly bound to the outer cuticular layer of fruits and vegetables. The research used papaya as a model, and found that the alkaline wash significantly decreased microbial load on the peel surface.

Teixeira (2006) compared browning susceptibility of fresh-cut carambola of seven genotypes and concluded that 'Arkin' was the least susceptible to browning. However, Weller et al. (1995) had an opposite observation that 'Arkin' was the most susceptible to browning out of nine genotypes of carambola that he studied. In this research 'Arkin' carambola was used since it is the leading commercial cultivar in Florida with sweet, juicy, firm flesh and with few seeds.

The objective of this study was to compare the quality of fresh-cut carambola affected by harvest maturity, pre-cutting sanitation, and post-processing anitibrowning/firming agent treatment.

Materials and Methods

PLANT MATERIALS AND PROCESSING. 'Arkin' carambolas were harvested from a commercial orchard in Pineland, FL, on 4 Sept. 2008 at full yellow stage, and again on 13 Jan. 2009 at color break (50% yellow) stage. All of the 120 fruits from each harvest were stored at 6 °C for 1 d prior to processing.

Processing was conducted in a 20 °C room and all contact surfaces were sanitized with 100 $\mu L \cdot L^{-1}$ peroxyacetic acid (PAA).

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Fruit were washed with 2% Fruit Cleaner 395 for 2 min (JBT, Lakeland, FL), rinsed in tap water (~20 °C) sanitized with 100 mg·L^{-1} sodium hypochlorite (chlorine) solution (pH 6.5–7.0) for 2 min, and rinsed with tap water. Then 60 out of 120 sanitized fruit were washed with a pH 12 alkaline solution for 1.5 min (10% SAF-FOAM, HDH Agri-Products, Tavares, FL), and rinsed with tap water. After removing stem and blossom ends, fruit were cut transversely into slices approximately 10 mm using sharp sterile stainless steel knives that were sanitized in 100 ppm PAA between each fruit. Immediately after cutting, slices were immersed in one of the following solutions at 8 °C for 2 min: (1) control, distilled water; (2) 0.1 M Ca ASA; and (3) 0.1 M ASA (color break fruit only). The slices were drained for 30 min, placed into polyethylene terephthalate trays (500-mL capacity) with two 6-mm holes filed with medical cotton and stored at 4 °C for 14 d. The slices were evaluated initially and twice during a 14-d storage period for visual appearance (surface browning), L*a*b* color values, firmness, TA, soluble solids content (SSC), and microbial counts. Each treatment consisted of three replicated trays containing 10 slices of carambola each per sampling day. For fruit harvested at color break, the total treatment/storage time combinations were 12, that is, 2 sanitation treatments (chlorine + alkaline vs. chlorine alone) × 2 post-processing dip treatments (Ca ASA and water) × 3 sampling times (days 0, 7, and 14). For fruit harvested at full yellow, 18 treatment/storage time combinations were used since an ASA post-processing dip treatment was added on these fruit to determine the effect of ASA alone (without calcium ions).

Quality evaluation. Quality analysis included visual quality, texture, color, SSC, and TA on days 0, 7, and 14.

Visual quality was rated on a 1–9 scale where: 9 = fresh, excellent; 7 = good; 5 = fair; 3 = poor; and 1 = unacceptable. A scale of 5 was considered the threshold level for marketability. For each replicate tray, 10 slices were evaluated and the mean values were used for statistical analysis.

Texture was determined using a texture analyzer (model XT2i; Stable Micro Systems, Godalming, UK), calibrated with a 5-kg weight and equipped with a 6 mm-diameter probe. The insert distance was 2.0 mm, with a stroke speed of 5.0 mm·s^{-1}. Five slices per replicate tray were used to measure firmness. Firmness was expressed in Newton (N).

Color of the cut surface was based on L*a*b* color value using a white tile calibrated chromameter (model CR-300; Minolta, Tokyo) using five slices per replicate tray.

SSC was measured using a digital, temperature-compensated refractometer (model PR-101; Atago Co., Tokyo) with freshly pressed juice from a single slice. Juice of five slices per replicate tray were used to measured SSC.

TA was measured titrating 10 g of juice squeezed from five slices per replicate tray using a stainless-steel garlic press and 40 mL deionized water with 0.1 mol·L^{-1} NaOH to pH 8.1 using a Sage dispensing system (ATI Orion, Boston, MA). Acidity was calculated as malic/oxalic acid (50/50: w/w).

Sensory evaluation was carried out at day 3 by an experienced panel of six members. Every member tasted two slices of fruit per treatment presented as coded samples, and selected the best flavor/taste treatment out of the two or three treatments presented.

Microbial analysis. Enumeration of microorganisms was performed as described by Narciso and Plotto (2005). Three fruit slices per replicate were washed in 99 mL of sterile phosphate buffer in a 950-mL sterile sampling bag (Fisherbrand, Fisher Scientific, Pittsburgh, PA). After gently agitating for 2 min, a sample of each buffer wash was plated on plate count agar (PCA) and potato dextrose agar (PDA) media using a Whitley Automatic Spiral Plater (DW Scientific, Ltd., Shipley, West Yorkshire, UK). The plates were incubated at 35 °C for 48 h and the results were read on a ProtoCOL colony counter (Synoptics, Ltd., Cambridge, UK).

Statistical analysis. SAS Version 9.1 (SAS Institute, Cary, NC) was used for analysis of data. For each quality or microbial attribute with three replicates, the main and cross effects of pre-cutting wash treatment (chlorine + alkaline vs. chlorine alone) × post-cutting dip treatment (Ca ASA, ASA or water) were analyzed using analysis of variance (PROC ANOVA) at each storage time. The treatment means were separated at the 0.001, 0.01 and 0.05 significance levels by least squares means test (LSD).

Results and Discussion

Compared to the water dips (control), the Ca ASA treatment maintained visual quality of carambola slices at 5.4 or higher scores, which are above the marketable threshold of 5.0, during the entire 14 d storage regardless of harvest maturity (Fig. 1). ASA treatment, only applied to the slices harvested at the yellow stage, also maintained visual quality over the 14 d storage at 4 °C (Fig. 1B). The control (water) slices had slightly lower scores compared with Ca ASA treatment when fruit were harvested at color break stage (Fig. 1A). However, for fruit harvested at the yellow stage, the control (water) slices had significantly lower quality scores and by 14 d storage had lost marketability (Fig. 1B).

A high a* value and low hue angle (both indicate a less green color), and a low L* value (darker color) were observed on the surface of slices with browning and dark visual quality whereas carambola slices that obtained higher visual quality scores (Ca ASA or ASA) had higher a*, hue, and L* values (Fig. 1, Tables 1 and 2). The discoloration of cut surface is considered to be a result of oxidation of polyphenol compounds due to PPO activity (Sapers, 1993; Toivonen and Brummell, 2008; Weller et al., 1997). After cutting, the compartmentalization of compounds in the cells of the wounded tissue begins to fail resulting in the mixing of polyphenol substrates with PPO which causes surface browning (Toivonen and Brummell, 2008). Ascorbic acid has been commercially used to control browning in fresh-cut carambola (Ding et al., 2007; Teixeira et al., 2008; Weller et al., 1997) and other fruits and vegetables (Baldwin et al., 1996; Toivonen and

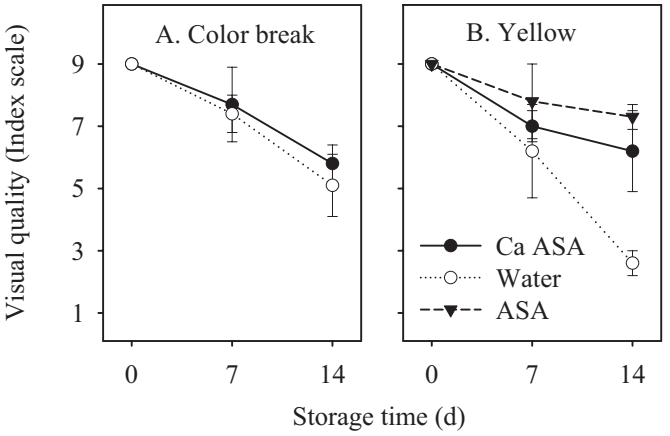

Fig. 1. Changes of visual quality of fresh-cut carambolas stored at 4 °C for 14 d. The fruit were washed with alkaline water before cutting, and dipped in calcium ascorbate (Ca ASA), ascorbic acid (ASA), or water after cutting. (**A**) harvested on 4 Sept. 2008; (**B**) harvested on 13 Jan. 2009.

Brummell, 2008). In addition, calcium is thought to maintain the integrity of the membrane system of cut fruit surfaces, and to alleviate browning (Martín-Diana et al., 2007; Toivonen and Brummell, 2008). However, our observations showed that there was no significant difference between the color (a*, hue and L*) of carambola slices treated with Ca ASA and ASA (Table 2). Similarly, previous results from Teixeira et al (2008) showed that calcium did not enhance anti-browning effects when used together with ascorbic acid. Ding et al (2007) showed that fresh-cut slices from more mature carambola fruit had higher PPO activity and more severe browning. This agree with our results which showed that color break fruit had less browning potential than yellow carambola after 14 d storage. Teixeira et al. (2005) reported that the best maturity stage for fresh-cut carambola was mature-green instead of riper stages, due to better color retention and maintenance of better appearance after cutting.

Cut slices from both maturity stages treated with Ca ASA maintained firmness throughout the entire 14 d of storage (Tables 1 and 2), but slices treated with ASA or water (control) showed a slight, but significant loss of firmness after 14 d (Tables 1 and 2). The higher firmness obtained for carambola slices treated with Ca ASA compared to the other treatments may be explained by the effects of calcium on cell wall membranes. Calcium dips maintained firmness of fresh-cut carambola probably via these two mechanisms: by providing ionic bridges between demethylated pectin molecules and by retarding senescence-associated membrane changes (Martín-Diana et al., 2007; Toivonen and Brummell, 2008).

Panelists preferred Ca ASA treated carambola slices over the water control when fruit were harvested at the color break stage (Table 3). However, for the fruit harvested at the yellow stage, there was no difference among Ca ASA, ASA and water treatments (Table 3). Slices from the control (water) fruit harvested at the color break stage had a sour, astringent, and bitter taste, and the Ca ASA treatment seemed to have alleviated this unpleasant taste. A possible explanation is that because fruit harvested at color break had higher titratable acidity than that fruit harvested at the yellow stage, the fruit organic acids may have reacted with calcium from the Ca ASA treatment and formed insoluble calcium oxalate. Evidence for this explanation is that fruit slices treated with Ca ASA had lower TA in comparison with other treatments (Fig. 2). These results agree with published research by Kaneta et al. (2006), which showed that a postharvest dip of calcium-chelate decreased oxalic acid and increased calcium content in carambola fruit. Our results also agree with those from Teixeira et al. (2005) who found that fruit harvested mature-green had poor taste compared with yellow fruit. However, Ca ASA treatment enhanced post-cut surface drying during storage.

The microbial populations on fresh-cut carambola fruit increased during storage at 4 °C, regardless the post-cutting dip treatment. The initial number of microorganisms was less than one log in all treatments (Tables 4 and 5). After 7 d storage, numbers reached log 4.48–4.82, and 4.13–4.63 in pre-cutting chlorine alone and chlorine + alkaline treatments, respectively (Tables 4 and 5). Each group of microorganisms increased similarly regardless of pre-cutting wash and post-cutting dip treatments. After 14 d of storage, the microbial population in cut carambola harvested at the yellow stage reached 5.25–5.61 and 4.64–5.20 logs, for the pre-cutting chlorine alone and chlorine + alkaline treatments, respectively (Table 5). Compared to the chlorine + alkaline wash, fruit slices treated with chlorine alone had < 1 log more microbial population throughout the storage except in the yellow stage cut

Table 1. Effect of post-cutting dip with calcium ascorbate (Ca ASA) and water on color and firmness of carambola slices during storage at 4 °C. Fruit were harvested on 4 Sept. 2008 at color break stage. Whole fruit were washed with alkaline solution

	Storage time (d)		
Treatment	0	7	14
	Color a value*		
Ca ASA	–4.3 a[z]	–4.1 b	–3.6 b
Water	–3.9 a	–2.9 a	–1.7 a
	Color hue angle (°)		
Ca ASA	102.6 a	105.9 a	101.8 a
Water	100.7 a	99.7 b	96.9 b
	Color L value*		
Ca ASA	46.1 a	45.8 a	46.0 a
Water	46.2 a	45.2 a	44.1 b
	Flesh firmness (N)		
Ca ASA	11.7 a	11.0 a	11.6 a
Water	10.8 b	10.6 a	10.1 b

[z]Values followed by the same letter within columns are not significantly different by the Fisher's least significant difference test at $\alpha = 0.05$.

Table 2. Effect of post-cutting dip with calcium ascorbate (Ca ASA), ascorbic acid (ASA) and water on color and firmness of carambola slices during storage at 4 °C. Fruit were harvested on 13 Jan. 2009 at yellow stage. Whole fruit were washed with alkaline solution.

	Storage time (d)		
Treatment	0	7	14
	Color a value*		
Ca ASA	–2.8 a[z]	–2.6 b	–2.0 b
ASA	–2.9 a	–3.0 b	–2.3 b
Water	–2.9 a	–1.7 a	–0.4 a
	Color hue angle (°)		
Ca ASA	100.3 a	99.6 a	100.2 a
ASA	102.1 a	100.4 a	103.2 a
Water	100.2 a	98.0 a	92.5 b
	Color L value*		
Ca ASA	47.5 a	46.0 a	45.8 a
ASA	48.2 a	47.1 a	45.9 a
Water	48.1 a	45.3 a	43.4 b
	Flesh firmness (N)		
Ca ASA	10.5 a	11.0 a	11.7 a
ASA	10.8 a	10.4 a	9.5 b
Water	10.8 a	10.7 a	9.8 b

[z]Values followed by the same letter within columns are not significantly different by the Fisher's least significant difference test at $\alpha = 0.05$.

Table 3. Effect of harvest maturity and post-cutting dip of carambola slices with calcium ascorbate (Ca ASA), ascorbic acid (ASA) or water on flavor and taste preference by 6 panelists. Slices were evaluated after 3 d storage at 4 °C. Fruit were harvested on 4 Sept. 2008 at the color break stage, or on 13 Jan. 2009 at the yellow stage. Numbers are number of panelists who preferred a particular treatment.

	Harvest maturity	
Treatment	Color break	Yellow
Ca ASA	6	2
ASA	---	3
Water	0	1
Total	6	6

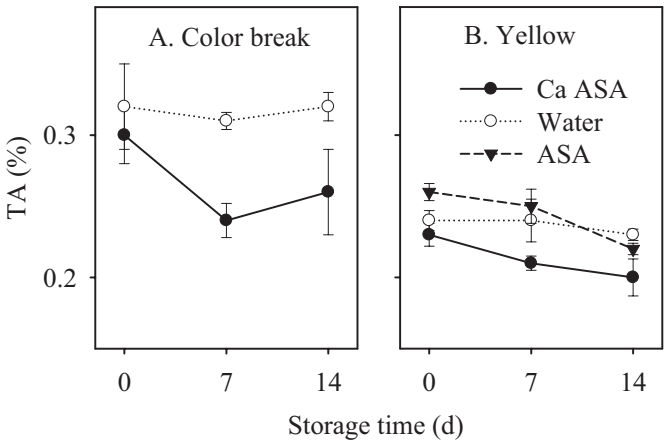

Fig. 2. Changes of titratable acidity (TA) content of fresh-cut carambolas stored at 4 °C for 14 d. The fruit were washed with alkaline water before cutting, and dipped in calcium ascorbate (Ca ASA), ascorbic acid (ASA), or water after cutting. (**A**) harvested on 4 Sept. 2008; (**B**) harvested on 13 Jan. 2009.

fruit stored 7 d where both treatments were the same for water and ASA dips. It has been shown that many contaminants in fresh cut and processed foods come from an inadequately cleaned peel. Spores and cells on the peel get transferred to the fruit during peeling and cutting and the containers often serve as an incubator for these organisms. Narciso et al (2009) looked at the peel of papaya through the scanning electron microscope (SEM) and found many microorganisms tightly bound to the outer cuticular layer. After washing the fruit in a strong alkaline solution, the majority of the contaminants carried on the outer cuticle were removed. Subsequent fresh-cut papaya slices produced using this pre-cutting procedure had significantly lower microbial counts and maintained a longer shelf-life (Narciso et al., 2009). The results from this research agreed with the previous research on papayas (Narciso et al., 2009). However, in a separate experiment (data not shown) the alkaline washed fruit showed chemical burn on the cut surface after 2 d storage at 14 °C, indicating phytotoxicity related to the high pH of the wash with longer exposure times.

Overall, both post-cutting ASA and Ca ASA dip treatments reduced microbial populations although only slightly (Tables 4 and 5). Acidification of the product surface is recommended to reduce microbial growth and ensure product safety (Soliva-Fortuny and Martín-Belloso, 2003). The ASA dip reduced microbial populations probably due to the reduced pH on the cut surface. Calcium salts showed decay prevention and sanitation effects on whole and fresh-cut fruit and vegetables in addition to their role as a firming agents (Martín-Diana et al., 2007). Conway and Sams (1984) reported that there is a close correlation between calcium content in stored apples and pathological disorders. Calcium chloride applications directly increased total and cell wall bound calcium of the fruit tissue. The effect of calcium in reducing decay is associated with maintaining cell wall structure by delaying or modifying chemical changes in cell wall composition (Conway and Sams, 1984). Calcium chloride has been used in whole and fresh-cut fruit and vegetables (Chardonnet et al., 2003; Conway and Sams, 1984; Garcia et al., 1996; Luna-Guzmán and Barrett, 2000; Saftner et al., 2003), but it has been associated with bitterness and off-flavors due to the residual chlorine remaining on the surface of the product (Bolin and Huxsoll, 1989; Ohloff, 1978; Ohlsson, 1994). Instead, calcium salts of organic acids such as calcium lactate, propionate, gluconate, and calcium amino acid

Table 4. Effect of pre-cutting chlorine (NaOCl) or NaOCl + alkaline wash and post-cutting dip with calcium ascorbate (Ca ASA), ascorbic acid (ASA), and water on microbial population (Log_{10} CFU/g) of carambola slices during storage at 4 °C. Fruit were harvested on 4 Sept. 2008 at color break stage. Whole fruit were washed with alkaline solution

Pre-cutting washing	Water	Ca ASA
	Day 0	
NaOCl	all < 1	
NaOCl + alkaline		
	Day 7	
NaOCl	4.71 a[z]	4.48 ab
NaOCl + alkaline	4.41 b	4.14 c
ANOVA (*F* value)[y]		
Pre-cutting wash (W)	15.31	***
Post-cutting dip (D)	11.27	**
W × D	0.09	NS

[z]Values followed by the same letter within storage day are not significantly different by Fisher's least significant difference test at $\alpha = 0.05$.
[y]***$P < 0.001$; **$P < 0.01$; NS, nonsignificant.

Table 5. Effect of pre-cutting chlorine (NaOCl) or NaOCl + alkaline wash and post-cutting dip with calcium ascorbate (Ca ASA), ascorbic acid (ASA) and water on microbial population (Log_{10} CFU/g) of carambola slices during storage at 4 °C. Fruit were harvested on 13 Jan. 2009 at yellow stage. Whole fruit were washed with alkaline solution.

Pre-cutting wash	Water	ASA	Ca ASA
	Day 0		
NaOCl	all < 1		
NaOCl + alkaline			
	Day 7		
NaOCl	4.82 a[z]	4.51 b	4.79 ab
NaOCl + alkaline	4.63 ab	4.45 b	4.13 c
	Day 14		
NaOCl	5.61 a	5.48 a	5.25 ab
NaOCl + alkaline	5.18 b	5.20 b	4.64 c
Anova (*F* value)[y]			
	Pre-cutting wash (W)	Post-cutting dip (D)	W × D
Day 7	37.61***	14.98***	15.18***
Day 14	30.76***	15.93***	1.81NS

[z]Values followed by the same letter within storage day are not significantly different by Fisher's least significant difference test at $\alpha = 0.05$.
[y]***$P < 0.001$; NS, nonsignificant.

chelate were suggested to result in similar firmness improvements without the disadvantages of calcium chloride (Anino et al., 2006; Manganaris et al., 2007; Saftner et al., 2003) (Yang and Lawless, 2005). Fan et al. (2005) and Plotto et al. (2003) used calcium ascorbate on fresh-cut apple and mango slices, respectively, which has both functions: preventing browning by the ascorbate and improving firmness and membrane maintenance by the calcium ions. In the current research, calcium ascorbate played an additional role by improving fresh-cut carambola taste by the binding of the free oxalic acid.

In conclusion, a supplemental whole fruit wash with alkaline water reduced microbial contamination on stored fresh-cut carambola slices. Dipping the slices in a solution of ASA or Ca ASA maintained visual quality of carambola slices from fruit harvested at the yellow stage by reducing browning, whereas Ca ASA improved the compositional quality of carambola slices

from fruit harvested at the color break stage by decreasing total acidity, probably by binding oxalic acid. However, this treatment also increased cut surface drying, but without negatively impacting the visual quality.

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