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ACIDIC FRUIT COATINGS FOR MAINTENANCE OF COLOR AND DECAY PREVENTION ON LYCHEES POSTHARVEST

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Abstract. **To maintain their red color postharvest, lychees harvested from groves in southern Florida can be successfully stored at 40°F for 10 to 15 days in vented plastic bags that promote a relatively high humidity. Should the pericarp dry, however, or become bruised or damaged from fungal infection, fruit rapidly turn brown and lose considerable value in the marketplace. As an alternative to foreign treatments in which fruit are decolorized with sulfur dioxide gas then dipped in acid to create a permanently fixed red pigmentation, fruit coatings can also influence the surface environment and color. Acidic coatings based upon cellulose, pectin, carrageenan, and sucrose esters were applied to lychees, reducing the surface pH from 5.0 to 3.3, which lasted throughout cold storage. With acid dips alone, the surface pH would eventually return to 4.8 due to the fruit's buffering capacity. Lychees coated with carrageenan and sucrose ester formulations developed less anthracnose decay in cold and ambient storage, and these coatings maintained the red hue of the fruit pericarp and the color intensity.**

The brilliant red pericarp of lychee (*Litchi chinensis* Sonn.) fruit quickly fades to a dull brown after harvest as dehydration and superficial decay promote cellular changes leading to the oxidation of anthocyanin pigments. Treatment with sulfur dioxide chemically bleaches all surface color and kills decay pathogens (Fourie, 1990; Schutte at al, 1991; Tongdee, 1994), and subsequent immersion in hydrochloric acid will restore and permanently fix the red hue, but sulfite residues also remain (Fourie, 1990, Underhill et al., 1992; Jiang et al., 1998). The use of vented plastic bags to maintain a high humidity around the fruit and cold storage can, in combination, maintain a fresh appearance for ten days or more without chemical alteration (Campbell, 1994). Another alternative for maintaining fruit color is the use of coating formulations, which, like bagging, help the fruit to retain moisture in the pericarp (Kester and Fennema, 1986). Conventional hydrophillic coatings of cellulose or sucrose esters, however, with near-neutral pH, fail to take advantage of the pigment chemistry and simply slow water loss to a modest degree (Kremer-Kohne and Lonsdale, 1991; York, 1994). If the fruit surface pH could be reduced to approximately 4.0, the anthocyanin pigments might become more resistant to fading.

By refomulating a coating of hydroxypropyl cellulose with an increased concentration of citric acid to achieve a pH of 2.3, the pH of the surface of 'Brewster' lychees was reduced to 4.85 (McGuire and Baldwin, 1996). As a result, the loss of pigmentation from the lychee pericarp was significantly slowed, even when fruit were held at room temperature. The significant buffering capacity of the pericarp, combined with the tendency of cellulose coatings to lose water, however, suggested a search for other coating formulations that might prove more efficacious. This paper reports results using a variety of coating polymers.

Materials and Methods

For initial comparisons, 'Bengal' lychees harvested from one tree at this USDA station were dipped in tap water of different pH, and color and decay were evaluated before and after storage. Twenty fruit were dipped for 5 min either in tap water or in water supplemented with 1 M HCl or 3% Na_2CO_3 and allowed to dry at ambient temperature. Surface color of each fruit was measured with a Minolta CR-200 chroma meter (Minolta Corp.; Ramsey, NJ) calibrated to a standard white reflective plate and recording in the L*C*h° color system (Lightness, Chroma, and hue angle, respectively); measurements were taken across an area of 50 mm^2 with diffuse illumination at a viewing angle of 0° under CIE (Commission Internationale de l'Eclairage) illuminant C conditions (McGuire, 1992). The surface pH of 10 fruit was subsequently

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measured with a flat-surfaced Orion combination electrode (Thomas Scientific, Swedesboro, NJ) 1 min after fruit had been re-wetted with distilled water. The fruit were then stored for 10 days at 5°C in vented plastic bags within vented cardboard boxes. After 10 days, color was measured again, and all fruit were rated for the percentage of surface decay with a 12-point visual acuity scale (Horsfall and Barratt, 1945). Fruit were then returned to the vented plastic bags for an additional 5 days of storage at 24°C. Storage was completed on the 15th day, and color and surface decay were again measured. At this time, surface pH was also measured from 10 fruit. A panel of 10 coworkers subsequently evaluated the internal and external appearance and taste of these fruit as previously described (McGuire, 1997). Panelists were asked to place a vertical mark on a 63.5 mm line; the line was bounded by "1" on the left end and "10" on the right, where "1" represented extremely substandard and "10" represented well above the standard.

A variety of fruit coatings was subsequently applied to 'Mauritius' and 'Brewster' fruit to determine the effect on color and decay after storage. The early-ripening 'Mauritius' fruit were harvested during May, 1997, from four farms in Dade County, Florida, whereas 'Brewster' fruit were harvested a month later from three farms. The farms represented experimental replications. With each replication, fruit were cut from the panicles and randomized into the various treatments.

One experiment with 'Mauritius' fruit compared acid-dipping and the use of cellulose coatings. Sixty fruit were dipped for 5 min in either 1 M HCl or in tap water then allowed to dry, and the surface color of 20 fruit from each portion was measured as described above. From each portion, 20 fruit were subsequently dipped by hand into coatings of 2% or 3% hydroxypropyl cellulose or were left uncoated. Solutions of 2% medium viscosity and 3% low viscosity hydroxypropyl cellulose (Klucel LF; Aqualon, Inc., Wilmington, DE) had been brought to a pH of 2.0 and 2.1, respectively, with 50 ml/L of citric acid, and 1% propylene glycol, 0.15% potassium sorbate, and 0.05% butylated hydroxyanisole (BHA) were added (Nature Seal™ formulations; EcoScience, Orlando, FL). After drying, fruit were stored as above at 5°C then at 24°C and subsequently evaluated for color changes. Surface pH was measured as described above.

A second experiment with both cultivars comprised fruit that were not acid-dipped. Coatings, besides the cellulose formulations above, included the commercial Freshseel (Agri-Coat Ind., Ltd., Great Shefford, Berks., England) based upon 0.26% sucrose-esterified fatty acid with a pH of 6.3, and formulations based upon 2% pectin (degree of esterification = 28%; Hercules, Inc., Middletown, NY) and 2% carrageenan (type 1 from Irish moss; Sigma Chemical Co., St. Louis, MO). The pectin and carrageenan solutions were dialyzed for 36 hr against distilled water changed every 12 hr then brought to a pH of 2.3 and 2.5, respectively, with 50% citric acid, after which propylene glycol, potassium sorbate, and BHA were added as above. Twenty lychees were hand-dipped in the various coatings or in tap water as a control, dried at ambient temperatures, then stored at 5°C. After 10 days, surface color of each fruit was measured as noted above, and all fruit were rated for the percentage of surface decay, then fruit were returned to the vented plastic bags for an additional 5 days of storage at 24°C. Storage was completed on the 15th day, and color and surface decay were again measured. At this time, surface pH was measured as described above.

Data were subjected to an analysis of variance (Proc ANOVA) using the SAS statistical software package (SAS, 1985) with means separation by the Ryan-Einot-Gabriel-Welsch multiple F (REGWF) test. After analysis, Horsfall/Barratt rating values were converted to mean percentages for estimation of percent surface area decayed.

Results and Discussion

Dipping lychees in HCl had an immediate effect on surface color (Table 1). Acid-dipping generally caused fruit to become slightly lighter (L* values were higher), but color intensity (C*) became significantly greater. Hue angle generally became smaller with acid treatment, indicating fruit were more red (h* of 0° is purple/red, 90° is yellow, 180° is blue green). Acid treatment significantly reduced the hue angle of the 'Mauritius' pericarp but not that of 'Bengal' and 'Brewster'; with treatment, color intensity was heightened for all cultivars, however.

Although the surface pH of uncoated 'Bengal' lychees could be temporarily altered by immersion in water at different pH, it would, over the course of storage, return to a value between 4.5 and 5.0 (Table 2). Nevertheless, this transient effect was sufficient to produce changes in fruit color during storage; as surface pH was reduced, fruit were lighter (higher L*), more intensely colored (greater C*), and more red (h° decreased toward 0). This effect persisted during cold and ambient storage. With decreasing pH of the immersion water there was also a direct effect on storage decay.

From the scores for external appearance (Table 2), it was apparent that fruit dipped in Na_2CO_3 were less attractive than other fruit after 10 days of cold storage; after an additional 5 days at room temperature, these fruit were too decayed to evaluate. Superficially, acid-dipped fruit looked very appealing throughout storage, but by day 15 there was frequently an internal brown discoloration that reduced rating scores. The taste of these acid-dipped fruit suffered in comparison with fruit dipped only in water; raters noted a metallic aftertaste.

Although acid-dipping alone did not preserve a lowered surface pH, the pericarp of fruit dipped in acid then coated with hydroxypropyl cellulose remained significantly more acidic with a pH near 3 versus a pH of 4.8 for uncoated fruit (Table 3). Whether dipped in acid or not, the two cellulose formulations, however, could not be distinguished based on

Table 1. Color comparison of 'Bengal', 'Mauritius', and 'Brewster' lychees at harvest.

	Pre-storage color[z,y]					
	Water-dipped			Acid-dipped		
Cultivar	L*	C*	h°	L*	C*	h°
'Bengal'	39.8 a	44.9 a	27.0 a	41.3 a	48.3 b	26.7 a
'Mauritius'	41.4 a	36.3 a	34.4 a	42.4 a	42.6 b	28.5 b
'Brewster'	35.7 a	37.8 a	26.6 a	40.3 b	45.7 b	24.8 a

[z]L*: lightness where greater values are lighter; C*: intensity where greater values are more intense; h°: hue angle where 0° is purple/red, 90° is yellow, and 180° is blue/green.

[y]Means of 40, 80, and 60 fruit ('Bengal', 'Mauritius' and 'Brewster', respectively); 20 fruit/replication. Within rows, color aspects (such as L*) followed by different letters are significantly different at $P \leq 0.05$ by analysis of variance in SAS.

Table 2. Quality of 'Bengal' lychees dipped in acidic and basic solutions prior to storage at 5°C for 10 days then at 24°C for 5 days.

		pH		Surface color[y]						Surface decay		Sensory evaluations[x]					
		Fruit surface		10 days at 5°C			+5 days at 24°C			10 days	15 days	10 days at 5°C			+5 days at 24°C		
		Initial	End	L*	C*	h°	L*	C*	h°	%	%	Appearance		Taste	Appearance		Taste
Treatment[z]												Ext.	Int.		Ext.	Int.	
1 M HCl,	pH 0.1	2.3 c	4.8 a	39.8 a	44.4 a	24.6 b	38.6 a	34.3 a	26.9 b	0.6 c	14.5 b	42.7 a	44.3 a	33.6 b	52.6 a	24.6 b	16.5 b
Tap water,	pH 8.9	4.5 b	4.9 a	38.2 b	45.1 a	26.2 a	35.7 b	34.6 a	28.6 b	2.5 b	32.3 b	46.3 a	51.5 a	51.7 a	20.9 b	48.8 a	46.0 a
3% Na_2CO_3,	pH 10.9	9.7 a	4.7 a	35.8 c	41.0 b	26.7 a	31.1 c	26.3 b	32.3 a	5.7 a	52.6 a	30.7 b	47.8 a	34.9 b	NT	NT	NT

[z]Means of 20 fruit. Mean separation at $P \leq 0.05$ within columns based on analysis of variance and the Ryan-Einot-Gabriel-Welsh multiple F test in SAS.
[y]L*: lightness where greater values are lighter; C*: intensity where greater values are more intense; h°: hue angle where 0° is purple/red, 90° is yellow, and 180° is blue/green.
[x]On a scale where 0 is extremely substandard and 63.5 is well above standard. Ext. = external. Int = internal. NT = not tested.

color response by the fruit. Ambient storage made fruit darker (lower L*), less intense (lower C*), and more orange (h° toward 90°). The cellulose coatings darkened fruit significantly but also kept them significantly (though only slightly) redder; color intensity was not affected.

Since acid-dipping tended to reduce the flavor of fruit, succeeding tests did not include this pretreatment but encompassed a greater variety of fruit coatings. Most impressive were the carrageenan and sucrose ester (Freshseel) coatings; these generally preserved the color intensity (greater C*) of 'Mauritius' fruit and kept fruit more red (h° lower), especially after ambient storage (Table 4). 'Mauritius' fruit are susceptible to anthracnose disease postharvest, and the pericarp often develops blackened spots of decay. Although coatings made with pectin and cellulose exacerbated early disease development, fruit coated with Freshseel and the carrageenan formulation developed the least decay. These findings were partially supported by work with 'Brewster' lychees (Table 4). The percentage of surface decay on 'Brewster fruit was lowest with fruit dipped in Freshseel and the carrageenan coating ($P = 0.06$).

The chemistry of the anthocyanin pigments is now well known (Simpson et al., 1976). The major anthocyanins that can be recovered from fresh 'Brewster' lychees have been identified as cyanidin-3-glucoside, cyanidin-3-rutinoside, and malvidin-3-acetylglucoside, which represent approximately 7, 68, and 10% of the total, respectively (Lee and Wicker, 1991). The remaining percentage is comprised of polymeric pigments, which increase during storage as the content of monomers falls. The composition of pigments would be expected to be different in other lychee cultivars, whose colors are visibly different. The stability of these pigments varies as well, with the acylated malvidin glucoside persisting longer in storage than the cyanidin glycosides (Lee and Wicker, 1991). Methoxyl substitutions in the molecule are also more stable than the hydroxyl substitutions found in the cyanidin glycosides (Simpson et al., 1976).

Table 3. Surface pH and color of acid- and water-dipped 'Mauritius' lychees subsequently coated with cellulose formulations and stored at 5°C for 10 days then at 24°C for 5 days.

	Surface	Surface color after 15 days[z,y]		
Fruit coating	pH	L*	C*	h°
Acid-dipped				
No coating	4.8 a	43.1 b	35.3 ab	34.0 a
2% cellulose	3.4 b	44.7 a	34.8 b	31.9 b
3% cellulose	3.4 b	43.4 ab	36.4 a	32.7 ab
Water-dipped				
No coating	4.9 a	38.0 a	29.4 a	39.1 a
2% cellulose	3.7 b	33.2 b	27.5 a	37.2 b
3% cellulose	3.2 c	33.9 b	28.7 a	37.3 b

[z]Means of 80 fruit. Within dips, mean separation at $P \leq 0.05$ within columns based on analysis of variance and the Ryan-Einot- Gabriel-Welsh multiple F test in SAS.
[y]L*: lightness where greater values are lighter; C*: intensity where greater values are more intense; h°: hue angle where 0° is purple/red, 90° is yellow, and 180° is blue/green.

Acidification of solutions of anthocyanins intensifies their color. For example, the pH of strawberry puree is the greatest factor affecting color loss; pH should be at or below 3.5 for retention of acceptable color after freezing and storage (Simpson et al., 1976). Pericarp tissue from 'Floridian' lychees with a pH of 4.1 was more red than similar tissue at pH 5.0 to 6.5 (Zauberman et al., 1991). Acidification not only alters the molecular structure of the pigment, it can inhibit polyphenol oxidase, which polymerizes the anthocyanins (Zauberman et al., 1991). Ascorbic acid, however, commonly found in fruits, accelerates the decomposition of anthocyanin pigments; it oxidizes to hydrogen peroxide which in turn oxidizes the anthocyanins (Simpson et al., 1976).

Dipping lychees in acid solutions is known to improve fruit color (Zauberman et al., 1990; Kaiser et al., 1995), but internal quality may suffer, as shown here and elsewhere (Torres et al., 1985). Acidic fruit coatings may serve a similar purpose but more gently (Underhill et al., 1992; McGuire and Baldwin, 1996). All coatings slow fruit dehydration and thereby help retain color, but acidic coatings affect the pigment molecule directly. The ability of the fruit to buffer residual surface acidity, however, will influence the effectiveness of any coating with respect to color. The cellulose molecule does not have acidic subunits, and acidity incorporated into this coating is more easily overcome than one made from carrageenan, which is inherently acidic. Coatings incorporating pectin might be expected to have different effects on color based upon the degree of methyl esterification of the pectinic acid.

Antimicrobial constituents of coatings, such as sorbic acid, are also more effective in an acid environment (Torres et al., 1985), although *Colletotrichum*, which is a major pathogen on lychees, itself is less able to grow under acidic conditions (Al Zaemey et al., 1994). This pathogen generally infects the fruit when they are young and lies dormant until the fruit mature (McMillan, 1994). *Penicillium*, on the other hand, infects

Table 4. Surface pH and color, and severity of surface decay, of 'Mauritius' and 'Brewster' lychees coated with acidic formulations and stored at 5°C for 10 days then at 24°C for 5 days.

		Surface color[y]						% Surface area decayed	
		10 days at 5°			+5 days at 24°			10 days	15 days
Cultivar/ Coating[z]	Surface pH	L*	C*	h°	L*	C*	h°		
'Mauritius'									
No coating	4.9 b	41.0 a	32.4 b	36.8 a	35.1 ab	21.0 c	50.7 a	19.4 bc	79.9 a
2% pectin	6.6 a	40.8 a	35.2 a	36.2 a	33.5 b	20.7 c	47.7 ab	49.1 a	83.3 a
2% cellulose	3.7 c	35.4 a	30.1 c	38.4 a	30.4 b	21.0 c	41.6 bc	34.3 ab	89.5 a
3% cellulose	3.2 d	37.9 a	31.3 bc	39.9 a	30.7 b	22.5 c	41.2 bc	42.1 ab	85.4 a
Sucrose ester	4.9 b	37.4 a	33.1 b	37.1 a	35.3 ab	30.6 b	36.8 cd	9.9 c	48.1 b
2% carrageenan	3.3 d	40.2 a	36.7 a	34.0 a	40.2 a	38.7 a	30.8 d	2.9 d	13.2 c
Brewster'									
No coating	4.8 b	34.6 a	37.2 ab	26.0 a	31.8 ab	23.1 ab	36.5 ab	10.2 bc	66.4 bc
2% pectin	5.5 a	34.2 a	34.6 b	27.4 a	33.2 ab	17.6 c	40.4 a	13.9 ab	86.3 a
2% cellulose	5.3 ab	32.5 a	37.0 ab	27.5 a	29.0 b	23.0 ab	34.3 ab	8.1 abc	78.7 b
3% cellulose	5.4 ab	32.7 a	36.8 ab	27.1 a	29.0 b	23.9 ab	33.0 ab	16.0 a	67.6 bc
Sucrose ester	5.4 ab	33.8 a	40.0 a	26.4 a	32.6 ab	26.8 a	35.7 ab	6.8 c	56.8 c
2% carrageenan	3.6 c	34.3 a	35.5 b	25.3 a	35.1 a	21.4 c	29.6 b	7.9 c	54.0 c

[z]Means of 80 fruit ('Mauritius') or 60 fruit ('Brewster'); 20 fruit/replication. Within columns of a cultivar, means followed by the same letter are not significantly different ($P \leq 0.05$) by analysis of variance and the Ryan-Einot- Gabriel-Welsch multiple F test in SAS.

[y]L*: lightness where greater values are lighter; C*: intensity where greater values are more intense; h°: hue angle where 0° is purple/red, 90o is yellow, and 180°is blue/green.

postharvest and could become a greater problem if the fruit surface is acidified. Sucrose esters are antimicrobial in themselves (Kato and Shitasake, 1975; Marshall and Bullerman, 1986; Al Zaemey et al., 1994); they are not suspected of any direct influence on anthocyanins, but can reduce pigment loss resulting from dehydration, oxidation, and the injurious effects of infection (Banks, 1984; Pavlath et al., 1993).

Owing to differences in pigment composition among cultivars, all lychees may not be expected to respond equally to fruit coating. Results with 'Brewster' lychees were not as impressive as those with 'Mauritius', but the latter cultivar is especially susceptible to anthracnose decay. Since it is an early cultivar as well, it is most valuable in the early market when high quality would bring a premium. Control of anthracnose in the field with fungicides may be possible, but the effects do not carry over into storage (Crane et al., 1997). With further improvements, acidic fruit coatings may find a significant niche in the lychee market postharvest.

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EFFECT OF COATING ON MANGO (*MANGIFERA INDICA* L.) FLAVOR

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Abstract. **Two types of fruit coatings were tested for their effect on internal mango fruit atmospheres and quality factors during simulated commercial storage at 10 or 15°C with 90-99% RH followed by simulated marketing conditions of 20°C with 56% RH. One coating was polysaccharide-based while the other had carnauba wax as the main ingredient. These two coatings reportedly differ markedly in O_2 and CO_2 permeability characteristics, with the polysaccharide coating being less permeable to respiratory gases. Both coatings created modified atmospheres, but only the polysaccharide coating seemed to delay ripening and increase the concentrations of flavor volatiles. Ethanol was increased 30-fold in polysaccharide-coated fruit compared to uncoated controls and 6-fold more than in carnauba wax-treated fruit. Sensory analysis showed that the polysaccharide-coated fruit were more sour, and chemical analysis revealed that these fruit had significantly lower pH and higher titratable acidity compared to the other treatments.**

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Mango (*Mangifera indica* L.) is one of the most favored specialty fruits in the U.S. (Vance Publications Corp., 1994) and is very popular world wide. (Mitra and Baldwin, 1997; Koulibaly et al., 1992).

Mango fruit are classified as climacteric and ripen rapidly after harvest. Disease susceptibility, sensitivity to low storage temperatures (below 13°C), and perishability due to ripening and softening limit transport distances from site of harvest (Mitra and Baldwin, 1997).

Mango external and internal quality is critical to consumer acceptability, and flavor is an important consideration when determining the price of the product (Gholap et al., 1986). Mango varieties differ in the amount and type of flavor compounds present, often depending on their origin. Generally, Old World (Asian) mangoes have more oxygenated aroma volatile compounds such as esters, furanones and lactones, giving some varieties pineapple- or peach-like aromas, while New World mangoes that are hybrids of Old World stock have higher levels of certain hydrocarbons such as 3-carene (Narain et al., 1998; Wilson et al., 1986; MacLeod and de Troconis, 1982) which are important for flavor (Malundo et al., 1996,1997).

Some extension of shelf life has been demonstrated using controlled atmosphere storage with relatively low O_2 and high CO_2 (Bender et al., 1997), however, CO_2 injury, increased ethanol production, and flavor problems due to anaerobic respiration have been reported (Bender et al., 1994; Lakshminarayana and Subramanyam, 1970). Concentration of flavor volatiles and/or flavor quality were affected by harvest maturity, controlled atmosphere storage (Bender et al., 1997), and storage temperature (Lakshminarayana, 1980).

Edible coatings are used on fruits and vegetables to extend shelf life and improve appearance (Baldwin, 1994). Coatings can retard ripening, water loss, and reduce decay (Baldwin et al., 1997; McGuire and Hallman, 1995), but may also alter flavor (Hagenmaier and Baker, 1993; Cohen et al., 1990). Semi-permeable coatings can create a modified atmosphere (Baldwin et al., 1995; Nisperos-Carriedo et al., 1990) similar to controlled atmosphere storage, with less expense incurred.

Coatings can indirectly induce changes in flavor due to delayed ripening or as a result of anaerobic respiration and accompanying increased ethanol concentrations as described