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LYCHEE COLOR CAN BE BETTER MAINTAINED IN STORAGE THROUGH APPLICATION OF LOW-PH CELLULOSE COATINGS

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Abstract. **Lychees, harvested in May and June, 1996, were coated with Nature Seal™ formulations designed to lower surface pH toward 4.0 and thereby prolong the red color of fruits throughout cold and ambient temperature storage. Coating formulations applied to 'Mauritius' fruit contained 2% low viscosity hydroxypropyl cellulose with a 0.075 M citrate buffer that maintained pH at either 3.31, 3.9, or 4.84. These treatments had little effect on fruit surface pH, which ranged from 6.0 early in the season to 5.7 at the end. However, a formulation of 3% medium viscosity hydroxypropyl cellulose with 0.1 M citric acid and a pH of 2.3 applied to 'Brewster' fruit significantly reduced surface pH as low as 4.85. Treated fruit in vented plastic bags maintained their color throughout 10 days of storage at 5°C (41°F). Fruit covered with this low-pH film also retained their red hue longer than uncoated fruit or those coated with the film of pH 4.84 during an additional 3 days at 24°C (76°F).**

Led by expanding markets near centers of Asian immigration, demand for lychee (*Litchi chinensis* Sonn.) fruit within the U.S. has doubled since 1990. Land under production in South Florida has risen from 160 acres in 1987 to 511 acres in 1995, from which 2,141 tons of fruit were harvested with a value of $8.57 million (Anonymous, 1996).

The appearance of lychees at the market catches the eye of the casual shopper, who often finds the bright red color appealing. Conversely, a display of lychees that appear dry and brown may be passed over by those unfamiliar with this fruit. Preserving the color of lychees is a prime consideration for successful marketing, and more postharvest research is focused on this quality aspect than on any other.

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The red anthocyanin pigment in the pericarp of lychees is degraded enzymatically when this exterior covering is injured or becomes desiccated (Fourie, 1990; Underhill and Simons, 1993). Injury may result from bruising, attack by postharvest pathogens, or excessive chilling during storage. Besides improving handling and storage procedures, color can be maintained through chemical means postharvest. Exposing fruit to sulfur dioxide gas inhibits enzymatic and non-enzymatic browning and controls decay microbes (Fourie, 1990; Schutte et al, 1991; Tongdee, 1994). Various methods have been examined, often in combination with hydrochloric acid (Fourie, 1990; Underhill et al, 1992; Jiang et al, 1997). The gas bleaches the fruit and inhibits polyphenol oxidase, then an immersion in acid of pH 0.3 to 1.0 permanently restores the red color (Zauberman et al, 1991). The surface pH after such treatment is 4.1 to 4.4.

Fruit coatings based upon sucrose esters or cellulose have not been found to affect the color of lychee pericarp in storage to any commercial advantage (Kremer-Kohne and Lonsdale, 1991; York, 1994). These materials, however, provide a convenient substrate for delivering and maintaining surface-active agents, such as fungicides, acidulants, or antioxidants, at the coated surface (Baldwin et al, 1995). Reducing the pH of these coatings from the range of 6.0 to 7.0 by incorporating an organic acid may improve color retention by lychees in storage.

The objective of this work was to develop low-pH coatings for lychees based upon Nature Seal™ formulations (Nisperos-Carriedo and Baldwin, 1994) incorporating hydroxypropyl cellulose and citric acid. The effect of these coatings on color retention by the pericarp, decay, and chilling injury was evaluated over prolonged storage periods using the two cultivars most widely grown in South Florida, 'Mauritius' and 'Brewster' (Knight, 1994).

Materials and Methods

In an initial trial, ripe 'Mauritius' fruit were harvested at three dates during May and June, 1996, from each of three farms in Dade County, Florida. The farms represented three experimental replications. At each harvest date 60 fruit were cut from the panicles and randomized. Surface color was recorded from 25 fruit per farm 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 ≈ 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 60 fruit were then sorted into four groups of 15. Besides an uncoated control, three treatments included fruit coated by hand-dipping them into 2% low viscosity hydroxypropyl cellulose (Klucel LF; Aqualon, Wilmington, DE) buffered with citric acid and sodium citrate to produce a coating pH of 4.84, 3.94, or 3.31 (Nature Seal™ formulations; EcoScience, Orlando, FL). To achieve the specific acidity, the formulation of pH 4.84 contained 0.03 M citric acid and 0.04 M sodium citrate, whereas formulations of pH 3.94 and 3.31 were prepared using 0.05 M citric acid and 0.03 M sodium citrate or 0.07 M citric acid and 0.01 M sodium citrate, respectively. Coated fruit were dried at ambient temperatures, then all fruit were stored at 5°C for 10 days in vented plastic bags within vented cardboard boxes.

After 5 days of cold storage, and again after 10 days, surface color of each fruit was measured as noted above. Storage was completed on the 10th day, and all fruit were rated for the percentages of surface bronzing, indicative of chilling injury, and surface decay with a 12-point visual acuity scale (Horsfall and Barratt, 1945). The surface of 10 fruit per treatment replicate was wetted, and after approximately 1 min the pH of these fruit was measured with a flat-surfaced Orion combination electrode (Thomas Scientific, Swedesboro, NJ).

'Brewster' fruit were similarly evaluated in a second experiment. Uncoated fruit were compared with fruit coated with either the 2% low- viscosity hydroxypropyl cellulose of pH 4.84 used previously or a 3% medium-viscosity hydroxypropyl cellulose of pH 2.3 derived from incorporation of 0.1 M citric acid. Fruit were stored as above at 5°C for 10 days then held in the vented plastic bags at 24°C for 3 additional days. The color of the pericarp was measured on day 5 and day 10 of cold storage and daily at 24°C. Also on day 10, the percentages of surface decay and chilling injury were noted, and the surface pH was measured. The experiment was replicated using fruit from three farms with three harvests per farm.

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 or injured by chilling.

Results

At harvest, the early ripening 'Mauritius' fruit were lighter in appearance with a less intense, less red hue than the later ripening 'Brewster' fruit. For these cultivars, the initial L*C*h° values of the pericarp prior to storage were 40.0, 32.5, 35.9 and 37.7, 39.1, 27.3, respectively, where for L* 100 is white and 0 is black, for C* 100 is most intense and 0 is least intense, and for h° 0° is red-purple, 90° is yellow, 180° is bluish green, and 270° is blue. After 5 and 10 days of cold storage, all fruit were darker and had a less intense color that was slightly more orange (Table 1). The color of uncoated 'Mauritius' fruit changed most dramatically within the first 5 days of storage, whereas the color of uncoated 'Brewster' fruit seemed to deteriorate more slowly.

When measured after 10 days of cold storage, 'Mauritius' fruit had a higher surface pH than 'Brewster' fruit (Table 1). The 2% low-viscosity hydroxypropyl cellulose formulations applied to 'Mauritius' fruit did not appreciably affect surface pH; however, a 3% medium-viscosity hydroxypropyl cellulose formulation of pH 2.3 reduced the surface pH of 'Brewster' fruit to 4.85.

The cellulose coatings affected the lightness aspect of surface color in cold storage (Table 2), darkening fruit slightly (Table 1). This darkening was counteracted for 'Mauritius' fruit by the cold storage, however, which enhanced lightness as storage increased. Coating treatments also reduced the color intensity (chroma) of 'Mauritius' fruit slightly but did not affect that of 'Brewster' fruit. The color intensity of 'Brewster' fruit declined as cold storage progressed.

Hue was the color aspect most variable among the farms that represented experimental replications (Table 2). For 'Mauritius' fruit, hue was also affected by time of harvest; fruit harvested later were more intensely orange (data not shown). Fruit of both cultivars became less red as the length of cold storage increased. There was no significant interactive effect between length of cold storage and coating treatment on hue for either cultivar, indicating little if any change in hue due to pH in cold storage. A slight reduction numerically in the loss of red hue from 'Brewster' fruit that was associated with lowered surface pH was not significant at this time.

Table 1. Surface pH and color, and susceptibility to chilling injury and decay, of lychee fruit coated with hydroxypropyl cellulose films of various pH and stored at 5°C for 10 days.

Cultivar/Coating	Surface pH[z]	Surface Color (L*C*h°: Lightness, Chrome, Hue)[z]						Percent Surface Area[z]	
		5 days at 5°			10 days at 5°			Injured	Decayed
'Mauritius'									
No coating	5.80ab	37.1	30.2	37.6	37.6	30.5	37.8	6.0a	1.0a
2% HPC, pH 4.84	5.90a	36.4	31.2	35.6	38.4	31.7	38.5	4.1a	1.4a
2% HPC, pH 3.94	5.83ab	35.6	30.8	34.8	37.2	32.5	36.4	3.5a	1.1a
2% HPC, pH 3.31	5.73b	36.0	31.0	36.9	36.2	30.9	38.3	2.9a	1.0a
'Brewster'									
No coating	5.46a	37.4	38.6	28.6	36.9	35.4	29.3	2.7a	2.3a
2% HPC, pH 4.84	5.42a	34.8	38.5	28.5	35.2	35.0	29.1	0.5b	3.9a
3% HPC, pH 2.30	4.85b	35.7	40.8	28.3	34.5	36.3	29.0	0.1b	2.8a

[z]Means of 45 fruit (pH of 30 fruit). Within cultivars, means followed by the same letter are not significantly different (P≤0.05) by PROC ANOVA and the Ryan-Einot-Gabriel-Welsch multiple F test in SAS.

Table 2. Analysis of variance of color characteristics of 'Mauritius' and 'Brewster' lychees during 10 days of storage at 5°C.

		L* (Lightness)		C* (Chroma)		h° (Hue angle)	
Cultivar	df	MS	F[z]	MS	F[z]	MS	F[z]
'Mauritius'							
Harvest	2	55.28	5.17	29.46	0.44	631.68	9.62*
Replication	2	35.67	3.33	147.91	2.20	382.55	5.83*
$Error_1$	4	10.70		67.19		65.66	
Treatment	3	7.27	2.81	6.03	3.75*	17.26	1.91
Harv*Trt	6	3.53	1.37	1.63	1.01	11.54	1.28
Rep*Trt	6	1.43	0.56	2.91	1.81	17.62	1.95
$Error_2$	12	2.58		1.61		9.02	
Storage day	1	20.66	14.26**	6.48	1.74	42.56	5.10*
Day*Trt	3	3.56	2.46	2.28	0.61	5.59	0.67
$Error_3$	32	1.45		3.72		8.34	
'Brewster'							
Harvest	1	2.24	0.05	58.12	0.66	0.33	0.72
Replication	2	22.31	0.48	79.47	0.91	26.49	57.28*
$Error_1$	2	46.64		87.74		0.46	
Treatment	2	15.74	36.89**	12.18	3.06	0.41	0.09
Harv*Trt	2	5.91	13.86*	2.31	0.58	3.46	0.72
Rep*Trt	4	1.08	2.54	2.05	0.51	2.74	0.57
$Error_2$	4	0.43		3.98		4.84	
Storage day	1	1.63	1.27	121.14	36.54***	3.64	6.04*
Day*Trt	2	1.79	1.40	1.67	0.50	0.01	0.01
$Error_3$	15	1.28		3.32		0.60	

[z]By PROC ANOVA in SAS. Effects significant at (*) P≤0.05, at (**) P≤0.01, or at (***) P≤0.001.

'Mauritius' fruit were more prone than 'Brewster' fruit to surface chilling injury but suffered less decay in cold storage (Table 1). Coating fruit did not affect decay. Fruit coated with hydroxypropyl cellulose tended to have less chilling injury than uncoated fruit, although results were more significant for the cultivar 'Brewster' than for 'Mauritius'.

To simulate handling within the supermarket, 'Brewster' lychees were held at 24°C within vented plastic bags. Such fruit became significantly darker, were less intensely colored, and lost a significant amount of their red hue, becoming more orange, as storage progressed (Table 3). As noted previously, coating with cellulose caused fruit to darken, but at this storage temperature retention of the red hue was significantly improved by coating the fruit. The rate of hue deterioration was reduced as surface pH declined (Fig. 1). Fruit harvested late were most susceptible to color loss at 24°C and most improved by coating (data not shown).

Discussion

Retaining the bright red color of lychees is paramount in attracting consumers to these fruit. Although color can be adequately maintained over 10 days in storage at 5°C if fruit are kept in vented plastic bags that maintain an adequate humidity (Campbell, 1994), they too often darken when placed in the dry, ambient environment characteristic of market shelves.

Table 3. Analysis of variance of color characteristics of 'Brewster' lychees during 3 days of storage at 24°C after 10 days at 5°C.

		L* (Lightness)		C* (Chroma)		h° (Hue angle)	
	df	MS	F[z]	MS	F[z]	MS	F[z]
Harvest	1	1.45	0.50	215.20	33.48*	138.88	3.02
Replication	2	12.94	4.45	13.77	2.14	96.70	2.10
$Error_1$	2	2.91		6.43		45.95	
Treatment	2	41.76	48.27**	0.79	0.30	255.83	52.18***
Harv*Trt	2	13.35	15.44*	20.19	7.71*	41.58	8.48*
Rep*Trt	4	2.62	3.02	13.66	5.22	4.65	0.95
$Error_2$	4	0.87		2.62		4.90	
Storage day	2	53.78	7.65**	552.91	40.40***	883.23	82.82***
Day*Trt	4	10.89	1.55	7.98	0.58	34.53	3.24*
$Error_3$	30	7.03		13.72		10.66	

		Surface Color (L*C*h°: Lightness, Chroma, Hue)[y]								
Coating	Surface pH[y]	1 day at 24°			2 days at 24°			3 days at 24°		
No coating	5.46	34.5	30.7	32.6	32.2	22.9	43.0	31.1	20.4	47.2
2% HPC, pH 4.84	5.42	32.4	30.0	32.0	29.1	22.0	38.9	32.0	21.0	49.2
3% HPC, pH 2.30	4.85	32.4	31.0	29.5	28.7	23.5	32.7	27.6	18.3	39.8

[z]By PROC ANOVA in SAS. Effects significant at (*) P≤0.05, at (**) P≤0.01, or at (***) P≤0.001.
[y]Means of 30 fruit.

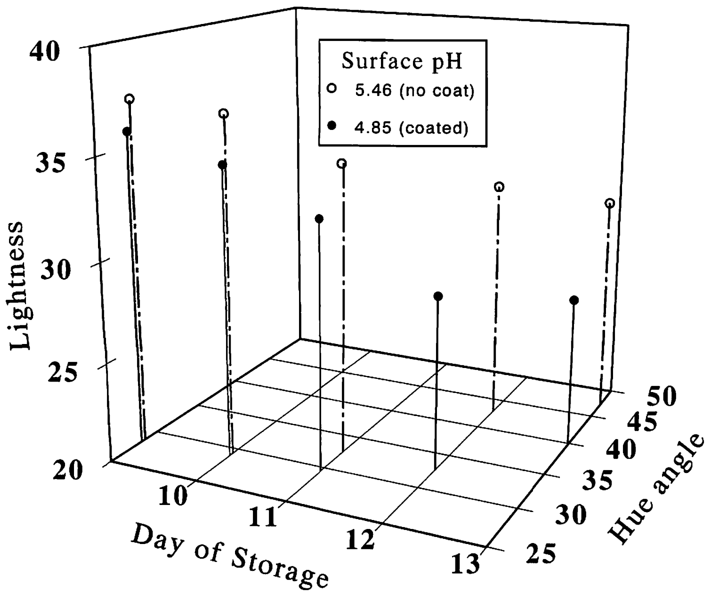

Figure 1. Lightness and hue aspects of the surface color of 'Brewster' lychee fruit during storage. Fruit, uncoated (O) or coated with 3% medium-viscosity hydroxypropyl cellulose at pH 2.3 (●), were stored at 5°C (41°F) for 10 days then placed at 24°C (76°F) for 3 additional days. Lightness increases from 0 to 100; redness decreases as hue angle rises from 0° to 90°.

Fruit coatings based upon wax or shellac seal pores within the fruit surface and restrict the loss of moisture (Hall, 1981). Cellulose coatings are hydrophilic and, therefore, less restrictive of water loss than wax or shellac coatings. Generally, this type of coating has a high water content, which enables it to initially sacrifice water from the coating and preserve that within the coated commodity (Kester and Fennema, 1986). Cellulose formulations also are more amenable than wax or shellac preparations to acidification below pH 5.0.

Although treatment with sodium sulfite and hydrochloric acid permanently fixes the anthocyanin pigment in the lychee pericarp, the introduction of sulfite is banned in fruit marketed in the United States (Fourie, 1990). One alternative is to acidify the fruit surface using a fruit coating. The target pH, similar to that of acid-treated fruit, is approximately 4.00. Citric acid, a natural ingredient already approved by the FDA as a food additive, can modify Nature Seal™ cellulose formulations within the range of pH 2.3 and 6.0.

Coating formulations of 2% hydroxypropyl cellulose containing a buffer system of 0.075 M citric acid/sodium citrate were insufficient, however, to appreciably lower fruit surface pH regardless of their acidity. The low-viscosity of this formulation caused only a thin film to form on the fruit surface, and the apparent buffering action of the pericarp was able to keep surface pH between 5.5 and 6.0. The slight pH change did not significantly affect the redness of 'Mauritius' lychees, although there was a trend toward a reduction of chilling injury as surface pH declined. By increasing the concentration and viscosity of the cellulose formulation, and by lowering its pH to 2.3 with citric acid, a reduction in the loss of redness by 'Brewster' fruit was achieved. The retention of redness was most significant at ambient temperature. These fruit also benefited from a reduction in chilling injury when cellulose coatings were applied.

Lychees are most susceptible to a loss of quality once they arrive at their point of sale where their environment is much less controlled. It is at this stage where cellulose coatings can be most useful, although the data suggest there may be less chilling injury in cold storage as well if surface pH can be lowered sufficiently. Future work will require the development and testing of various coating materials that can deliver sufficient acid to overcome the buffering capacity of the lychee's pericarp yet coat the fruit easily. Cellulose coatings can be easily adapted to deliver a low pH by incorporating citric or ascorbic acid; substitution with polyelectrolytes such as pectic acid and carrageenan should also be considered.

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