Proc. Fla. State Hort. Soc. 117:396-402. 2004.

A REFEREED PAPER

FRUIT COATINGS CONTAINING AMMONIA INSTEAD OF MORPHOLINE

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Additional index words. Citrus, ethanol, fruit flavor, pomelo, propylene glycol

Abstract. **The use of morpholine in fruit coatings in the U.S. is common, however ammonia can be used instead. Resin coatings were made from aqueous ammonia solutions of shellac and wood rosin. The affect of rosin coatings on internal gas concentrations was found to be highly variable, depending on the amount of plasticizer added—thus opening the possibility of developing a rosin coating of citrus fruit that is more flavor-friendly. Wax coatings were made from ammonia-based anionic microemulsions of various waxes, with emphasis on carnauba wax. Preparation of these microemulsions involved development of a new laboratory method for their preparation as well as selection of the most appropriate fatty acids. For carnauba-wax coatings, which consist partly of fatty acids, the optimum formulation consisted of a mixture of oleic, lauric and myristic acids, with total fatty acid content equal to about 14% of the wax. Carnauba wax coatings allowed for optimum exchange of gases on pummelo fruit. These ammonia-based fruit coatings were also successfully tested on apples, oranges and grapefruit. The results indicate that morpholine is not a necessary ingredient of fruit coatings.**

Carnauba wax coatings are widely used for both apples and citrus fruit. Morpholine has been used in carnauba wax coatings for about 50 years (Newhall and Grierson, 1955), and continues to be so used. Out of about 60 samples of commercially-available citrus and apples coatings received in our laboratory over the past ten years, over 90% contained morpholine. Morpholine, in fact, has been used for over 50 years as a base to ionize fatty acids, a required step in manufacture of anionic carnauba-wax microemulsions (Eaton and Hughes, 1950; Treffler, 1952).

The approval for morpholine as a component of protective coatings for fruits and vegetables requires that it is used as the salt(s) of one or more of the fatty acids (FDA, 21 CFR.172.235). However, fruit coatings were found to contain an average of 2.9% morpholine (Kielhorn and Rosner, 1996). The regulation would seem to imply that the fatty acids and morpholine should be present in roughly equimolar levels, but that would be equivalent to 9.4% fatty acid (oleic acid equivalent). Because the fatty acid content is much less than that, it seems possible that some reduction in morpholine usage might be in the cards.

A second advantage of morpholine is low volatility (the boiling point is128 °C), which makes it makes it easy to store coating microemulsions in inexpensive containers. Ammonia, on the other hand, evaporates very rapidly (boiling point = -37 °C), especially at the high temperatures (about 95 °C) needed to formulate carnauba wax microemulsions. Even at ambient temperatures, ammonia evaporates from coating formulations fast enough to make it necessary to keep them tightly closed. Ammonia vapor is unpleasant, toxic and, in addition, can cause false alarms in packinghouses that use human detection of its odor as a warning that the ammonia-based refrigeration system is leaking. Even so, there are good reasons for using ammonia rather than morpholine, but first a comment on why ammonia should even be considered as an appropriate alternative.

The wax formulations accepted as most useful for fruit coatings are anionic microemulsions that consist of water, wax, and soap (consisting of fatty acid anion plus appropriate cation). After application to fruit, these dry to form a coating, but the coating would consist largely of water-dispersible soap if the cationic moiety consists of inorganic cations like potassium or sodium. In order for the coating to be water resistant, it is preferable to use ammonia or an amine, which acts as a cation in aqueous solution but evaporates as the coating dries. Thus, ammonia meets the chemical demands. Ammonia also is widely approved by federal and international agencies (Table 1).

Morpholine has more limited approval. Like other amines, it can react to form carcinogens, in this case N-nitrosomorpholine (Kielhorn and Rosner, 1996). At present, the EU does import fruit from the U.S. coated with morpholine-based coatings, even though these cannot be applied in European packinghouses.

The purpose of this paper is to investigate the possibility of formulations for coatings that contain no morpholine. Some such formulations were previously reported (Hagen-

Table 1. Regulatory status of ingredients in fruit coatings.

	FDA[z]	EU[y]	Japan[x]
Ammonium hydroxide	21 CFR 184.1139 (GRAS)[w]	E527	None[v]
Beeswax	21 CFR 184.1973	E901	No. 431
Candelilla wax	21 CFR 184.1976 (GRAS)	E902	No. 112
Carnauba wax	21 CFR 184.1978 (GRAS)	E903	No. 104
Dimethyl polysiloxane	21 CFR 173.340	E900	None
Fatty acids	21 CFR 172.860	E570	No. 165
Morpholine	21 CFR 172.235	None	None
Paraffin	21 CFR 178.3710	None	No. 451
Polyethylene wax	21 CFR 172.260	E914	None
Shellac	None	E904	206
Wood rosin	21 CFR 172.210	None	None

[z]Food and Drug Administration.
[y]From the Fed. of European Food Additives and Food Enzymes Industries.
[x]Ministry of Health and Welfare (Japan).
[w]Code of Federal Regulations. GRAS = generally recognized as safe.
[v]No official approval is known.

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

maier and Baker, 1997) but this study presents additional formulations and data.

Materials and Methods

Coating formulation. The shellac coatings were made by adding plasticizer to aqueous ammonia solutions of shellac (Tigerlac 5050 dewaxed bleached shellac, Kane International Corp., Tampa, Fla.), which also contained 40 ppm antifoam. Wood rosin coatings were similarly made with the pentaerythritol ester of maleic anhydride-modified wood rosin (Pentalyn FC, Hercules, Inc., Wilmington, Del.) replacing the shellac.

Wax microemulsions were made with ammonia in three different ways. The first method was a version of the classic 'pressure' method (Burns and Straus, 1965). A two-liter stirred pressure cell (Parr Instrument Co., Moline, Ill.) was loaded with wax, selected fatty acids, ammonia, and an amount of water approximately equal to the weight of the wax. This was heated to about 20 °C above the melting point of the wax, with stirring. Sufficient hot water (about 90 °C) was added to invert the emulsion from water-in-wax to wax-in-water and simultaneously dilute it to about 25% total solids. It was stirred for five minutes, and cooled to 50 °C, stirring throughout. This method was useful for all types of wax.

Two other methods were used for waxes having melting points above that of carnauba wax (85 °C). The pressure/atmospheric method followed the same procedure except that the amount of water used initially was twice the weight of the wax, the mixture was mixed for 20 min above the melting point of the wax, and the pressure cell was cooled to about 95 °C and it was opened to the atmosphere before additional water was added to invert and dilute the microemulsions. The advantage of this method was that because the cell was open to atmosphere, it was easier to add the additional water.

The third method, which did not require a pressure cell, was similar to the classical, atmospheric water-to wax method (Eaton and Hughes, 1950), with special precautions to deal with ammonia volatility. Into a 240 mL aluminum beverage can (6.6 cm diameter × 15.5 cm high, walls 0.12 mm thick) the following ingredients were added: 40 g wax, 15 g water, fatty acids and 0.15 g of 5% antifoam (polydimethylsiloxane). This was submerged to a depth of 13 cm in a 105 °C water bath and 28 g of 8% ammonium hydroxide was very slowly added, followed by 160 mL hot (about 85 °C) water to invert the emulsion. The mixture was stirred with a 35 mm diameter propeller at 800 rpm throughout the procedure: for 5 min to melt the wax and heat the contents to about 90 °C, for three minutes while adding the ammonia solution, for about one minute while adding hot water, and for two minutes of final mixing. The resulting microemulsion was cooled to 50 °C in an ambient-temperature water bath. For an initial evaluation of quality, the microemulsion was visually examined, weighed to calculate its concentration, and measurements made of pH and turbidity.

Treatment of fruit. The citrus fruits were grown in Polk County, Fla. These consisted of 'Valencia' oranges [*Citrus sinensis* (L.) Osbeck cv. Valencia] and 'Marsh' grapefruit [*C. paradisi* Macf.]. Two types of pummelo (*C. maxima* or *C. grandis*) were obtained the Florida Citrus Arboretum (Winter Haven, Fla.); these were and 'Kao Phuang' and 'Siamese,' clone nos. DPI-483-5-2(STG) and DPI-438-6-9A, respectively. The 'Red Delicious' apples (*Malus domestica* Borkh) were transported by refrigerated truck from Washington, courtesy of Publix, and stored for 1 week at 1 °C for before application of coatings.

The fruit were washed in our laboratory with brushes, using Decco Fruit & Vegetable Kleen 241 (Elf Atochem, Monrovia, Calif.). Before application to fruit, water was added to experimental coatings to adjust these to 20% total solids, except for some pummelo coatings. For comparison, commercial carnauba wax coatings were also used, including 'Brilliance' (CH2O, Inc., Olympia, Wash.) and Natural Shine 9000 (Pace International, Seattle, Wash.). Coatings were spread on each piece of fruit by hand (using latex gloves) and dried in a hot-air dryer at 50 °C, residence time 5 min. The fruit were weighed a few seconds just before and after putting on the coating to monitor the amount applied, which was about 0.3 g for oranges and apples, 0.4 g for grapefruit and 1.1 g for pummelos fruit. These amounts of coating resulted in about 0.3 mg cm^{-2} of dry coating, calculated from wet weight and known solids content. This amount of coating was typical of the amount of coating applied in Florida citrus packinghouses (Hagenmaier and Baker, 1994a). The coated fruits were stored at 20 °C, 50% relative humidity.

Gas Analysis. Samples for internal O_2 and CO_2 were withdrawn by syringe (previously flushed with N_2 to remove traces of oxygen) from fruit that were submerged in water. The O_2 and CO_2 concentrations were measured with a Hewlett Packard 5890 gas chromatograph fitted with a CTR-1 column (6 ft long, 1/4" and 1/8" diameter, outer and inner columns, respectively, Alltech, Deerfield, Ill.). Samples were applied with a 250 µL loop injector. Column flow rate was 100 ml min^{-1}. Temperatures were 70 °C and 120 °C, respectively, for the column and thermal conductivity detector. Peak areas obtained from standard gas mixtures were determined before and after analysis of the samples. Oxygen concentration was calculated from the O_2-Ar peak area. The values reported for individual fruit are the means of two determinations.

Ethanol content was determined by analysis of juice from stored fruit. The juice was spiked with n-propanol at concentration of 900 mg kg^{-1} as an internal standard. Ethanol concentration was determined by gas chromatography (Auto System, Perkin Elmer, Corp., Norwalk, Conn.). Sample volume was 1 µL, injected at 10:1 split ratio, 9 mL min^{-1}. The column was EC1000 (Alltech, Deerfield, Ill.), 30 m × 0.53 mm diameter, sample applied at 55 °C, with 3 °C min^{-1} rise in temperature. Injector and FID detector temperatures were both 250 °C. Ethanol concentration was calculated from area ratio of ethanol and n-propanol, calibrated from the same ratio from known standards.

Microemulsion turbidity was measured (n = 2) in nephelometer turbidity units (NTU) with the Hach Ratio/XR Turbidimeter (Hach Co., Loveland, Colo.). Globule size measurements (n = 1) were made with a model LS 230 particle size analyzer (Beckman Coulter, Inc., Fullerton, Calif.). Amount of coating lost by flaking was measured (n = 6) by bumping and rubbing together a pair of fruit from the same treatment, wiping the fruit with a cloth, and measuring the nearest 0.1 mg the weight uptake. The reported means are based on 2 measurements each on 3 different pairs of fruits.

Gloss was determined with a reflectometer (Micro-TRI-gloss, BYK Gardner, Silver Spring, Md.). This unit was calibrated on the standard surface, supplied with the instrument and the sensor covered with a shield having an 18 mm diameter hole to block out stray light. Gloss Units (G.U.) were measured (n = 100) at an angle 60° to a line normal to the

fruit surface. The reported means are based on 20 measurements on each of 5 different fruits).

Statistix7 (Analytical Software, Tallahassee, Fla.) was used for analysis of data.

Results and Discussion

Rosin and shellac coatings. The gas exchange of ammonia-based rosin coatings for citrus fruit depended much on the amount of plasticizer added (Fig. 1), however the results were opposite of previous findings that added plasticizer increased oxygen permeability (Park and Chinnan, 1990). Higher O_2 and CO_2 permeability would result in elevated internal O_2 and decreased internal CO_2 with increasing plasticizer, the opposite of what was found. The explanation is that the coatings tended to become discontinuous and flake off when insufficient plasticizer was used (Fig. 2). This is a new finding, and seems important because many, if not most, Florida citrus coatings contain large amounts of wood rosin, and these coatings generally inhibit gas exchange to a degree that internal O_2 concentration becomes too low to support aerobic respiration, with resulting flavor problems (Baldwin et al. 1995; Cohen et al., 1990a,b; Cuquerella-Cayuela et al., 1983; Hagenmaier 2000 and 2002; Hagenmaier and Baker, 1994b; Shaw et al. 1991, 1992). Present results suggest that with minimal plasticizer it may be possible to find a suitable compromise between optimum appearance and shine on one hand, and optimum flavor on the other. The same approach might be used with morpholine-containing coatings.

Carnauba wax coatings. Selection of the proper fatty acid was very important in preparation of ammonia-based carnauba wax microemulsions of low turbidity, which is of some importance because turbidity is a useful first-estimate of coating quality. Wax emulsions of high turbidity, especially those white in color, are not used as coatings by the industry. That bit of conventional wisdom was accepted as a given. The present work included the preparation, by trial-and-error adjustments, of over 150 carnauba wax microemulsions with

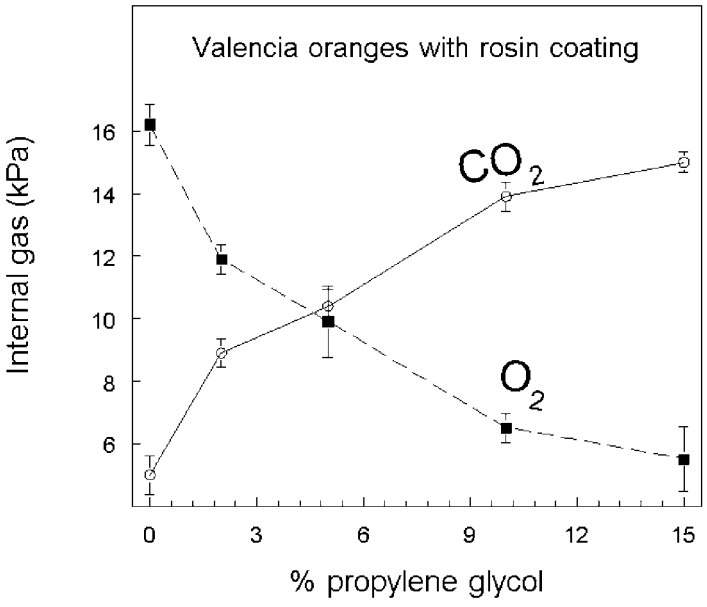

Fig. 1. Internal gas concentrations of 'Valencia' oranges stored at 20 °C, 50% relative humidity for six days.

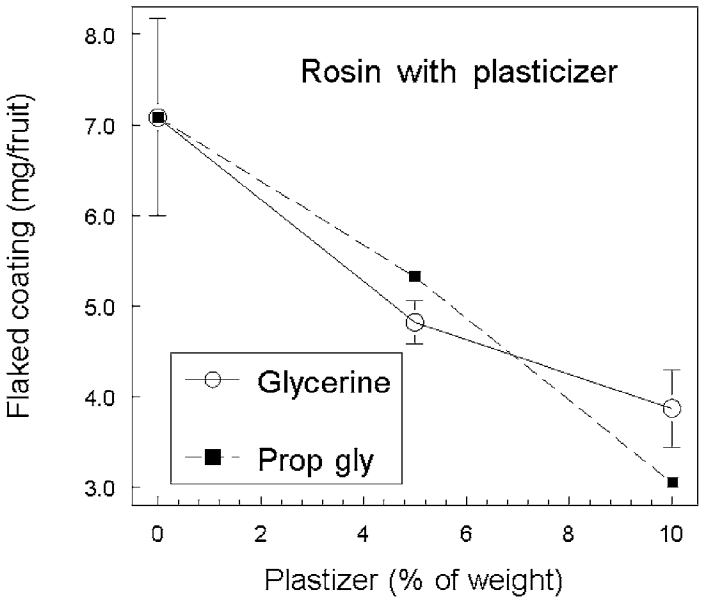

Fig. 2. Flaking of wood rosin coatings on 'Valencia' oranges, weight of removed coatings.

different formulations. It was found that low-turbidity, ammonia-based carnauba wax microemulsions were successfully made only with combinations of food-grade oleic acid with myristic and/or lauric acid (Tables 2 and 3). By contrast, preparation of morpholine-based carnauba wax emulsions was possible with food-grade oleic acid as the only source of fatty acids (Hagenmaier, 1998). This result suggests that the morpholine soap of oleic acid was more effective than the ammonium soap as an emulsifier. The emulsification properties of fatty acid soaps, therefore, depend on the identity of both the cation and the fatty acid. This may explain why ammonium laurate was a successful emulsifier in our laboratory despite the conclusion by Treffler (1952) that lauric acid was ineffective; his conclusion was based on use of amine soaps of fatty acids, not the ammonium soaps.

The atmospheric method for making the carnauba-wax microemulsions was an important tool in preparing these formulations. The main difficulty in making ammonia-based microemulsions by the atmospheric water-to-wax method is the vaporization of ammonia. The method as described circumvents this difficulty by having sufficient water present to ab-

Table 2. Turbidity of some carnauba wax microemulsions made with the atmospheric or pressure-atmospheric method.

	Turbidity and composition of selected emulsions			
		Food grade fatty acid content (% of wax)		
Carnauba grade	Turbidity (NTU)	Oleic	Myristic	Total
T4[z]	233	3.5	10.5	14
T3[y]	189	4.5	13.5	18
T4[z]	519	12.0	8.0	20
T3[z]	404	10.0	10.0	20
T4[z]	185	10.0	10.0	20
T3[y]	170	5.0	17.0	22

[z]Made by the atmospheric method.
[y]Made by the pressure-atmospheric method.

Table 3. Turbidity of ammonia-based, anionic carnauba wax microemulsions made with mixtures of lauric acid and food grade oleic using the atmospheric method.[z]

Type of carnauba wax	Turbidity (NTU)	Food grade fatty acid content (% of wax)		
		Oleic	Lauric	Total
T3	748	4.0	6.0	10.0
T4	439	7.2	4.8	12.0
T4	366	7.3	7.3	14.5
T4	212	11.2	5.0	16.2
T4	121	14.0	6.0	20.0
T3	228	14.3	7.7	21.0
T4	171	16.8	7.2	24.0
T4	205	14.3	11.7	25.0

[z]So-called food grade 'oleic' acid: 'oleic' and 'lauric' acids consisted of about 75% and 98% of the principal fatty acid, respectively, with the balance as other fatty acids.

sorb the ammonia, but not so much that the emulsion has advanced to the wax-in-water condition. That the method was successful is shown by the fact that no apparent differences were detected in the wax microemulsions made by the three methods (Tables 2-4). Because the atmospheric method was relatively easy and fast, it was possible to try many different formulations could be tried, thus making it possible to determine which formulations worked and which did not.

Gloss of the Wax Coatings. When a wax microemulsion dries to make a wax coating on the skin of a fruit, it seems reasonable to expect that the globule size be much less than the thickness of the coating. Fruit coatings applied to Florida citrus were observed to have a mean surface density of about 0.3 mg cm^{-2} dry weight (Hagenmaier and Baker, 1994a), which corresponds to a thickness of about 3 µm. The globule size of microemulsions can be roughly estimated by the naked eye: if translucent or opalescent, the globule diameter is less than about 140 nm, (Prince, 1977). The microemulsions used in this study were, in fact, translucent. The globule sizes were also measured, with results similar to those that might be predicted from their appearance (Table 3).

It is important to fruit marketing that coatings impart gloss, thus making the fruit or vegetable appear to be more 'fresh.' Fruit coatings made with lauric-oleic carnauba wax microemulsions had good gloss with fatty acids present in the amount of about 15% of the wax, based on the gloss of coated grapefruit (Figs. 3 and 4). The gloss decreased as the amount of fatty acid was increased from 16% to 26% of the wax ($P < 0.01\%$). By comparison, the mean gloss of NS9000 and Brilliance coatings were 7.7 and 7.8, respectively, not significantly different from the gloss of the T3 or T4 coatings with fatty acids present in the amount of 13-16% of the wax.

Although higher gloss was obtained with the more turbid experimental coatings (Figs. 3 and 4) that does not contradict the conventional wisdom that low turbidity (and smaller globule size) is better (Prince, 1977). Rather, the conclusion is that the low-fatty acid carnauba emulsions had higher gloss despite their higher turbidity.

Of the many ammonia-based carnauba wax formulations that were made and tested, the best gloss obtained with T4 rather than T3 carnauba wax, and about 14g total fatty acid per 100 g carnauba wax (Figs. 3 and 4), with a lauric acid/myristic ratio of about 2.7:1 (Fig. 5). For minimum weight loss, about 14g fatty acid per 100 g carnauba wax was optimum (Fig. 6). A coating filling these criteria contained 14 g fatty acid per 100 g carnauba wax, made up of 6.2, 5.7, and 2.1 g each of food-grade oleic, lauric and myristic acids, respectively. This coating gave about the same gloss on apples as commercial, morpholine-based coatings (Fig. 3 and Table 6).

Attempts to make other microemulsions with similar fatty acid content showed that very little deviation from this composition was possible. For the formulation described, the food-grade oleic acid constituted 43% of the fatty acids. Alternate formulations with oleic acid as 46 and 50% of the total fatty acids also gave low-turbidity emulsions that seem usable as coatings. However, formulations with 36 or 57% oleic made turbid emulsions. By contrast, when using more fatty acids, low-turbidity emulsions could be made with a wide range of percentage oleic acid (Table 2). These results suggest that rather close tolerances on the fatty acid composition are imposed when using making an emulsion with relatively low amounts of these.

Beeswax coatings. Microemulsions with beeswax alone, not mixed with carnauba wax, had rather high turbidity. The lowest turbidity achieved with beeswax as the only wax was 50,000 NTU, this for a microemulsion made with 8 g food-grade oleic acid, 6 g lauric acid and 6 g caprylic acid per 100 g beeswax. This emulsion separated into 50% white cream and 50%

Table 4. Mean diameter of globules in ammonia-based microemulsions.

		Fatty acid (g/100 g wax)			Microemulsion properties		
		Oleic	Lauric	Myristic	Visual	Globule dia. (µm)	Turbidity (NTU)
A	Carn T3	8	0	14	Translucent	0.07	1876
B	Carn T3	12	0	8	Translucent	0.12	561
C	Carn T3	15	0	5	Translucent	0.12	1440
D	Carn T4	10	10	0	Clear	0.12	213
E	Carn T4	14	12	0	Clear	0.12	101
F	Beeswax-Carn[z]	14	0	6	Clear	0.12	198
G	Paraffin-PE[y]	13	0	7	Clear	0.12	438
H	Candelilla wax	13	0	7	Clear layer (85%)[x]	0.07	230
					Cream layer (15%)	0.2 to 0.8	white

[z]Made with 50% Carnauba T3.
[y]Made with 60% paraffin and 40% polyethylene (AC680).
[x]Separated by gravity into two layers, 85% clear and 15% cream, which was white in color with turbidity too high to measure. For the mixture, 92% had 0.07 µm dia.

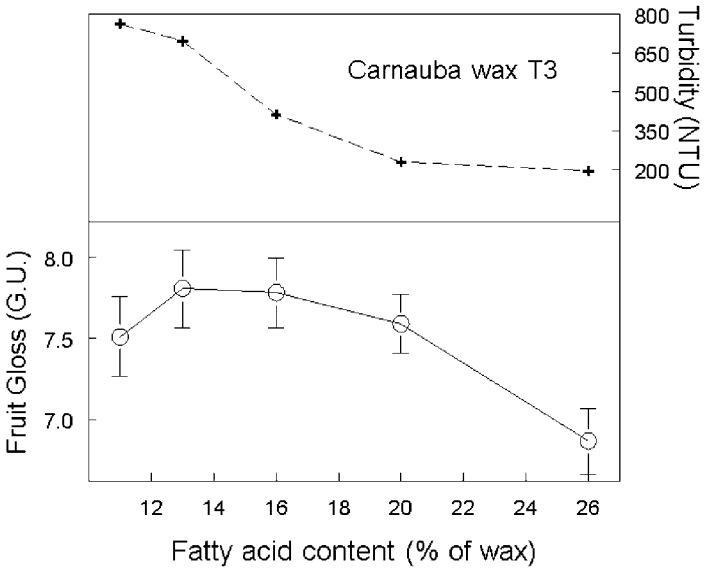

Fig. 3. Mean gloss and turbidity of grapefruit with wax coatings made from grade T3 carnauba wax, based on 100 readings of G.U. at 60 °C for each coating. The mean gloss values for grapefruit with commercially-available T3 carnauba wax coatings were 7.7 and 7.8, respectively.

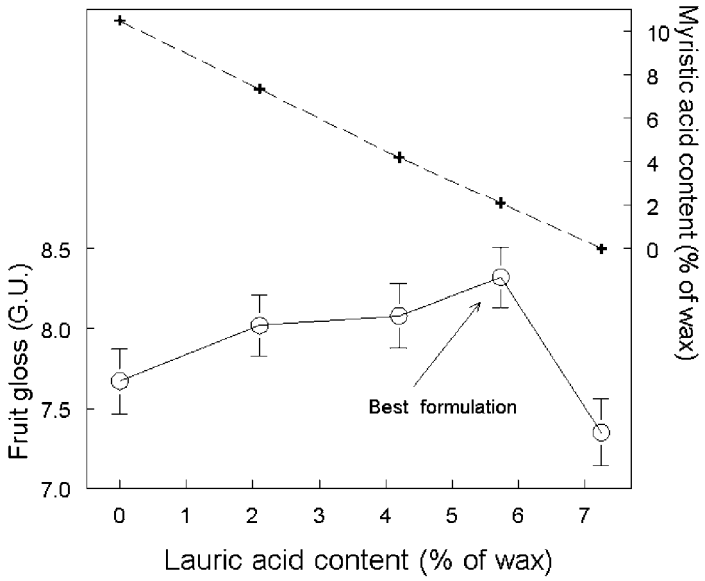

Fig. 5. Gloss on grapefruit of carnauba wax T4 coatings made with coatings containing different amounts of lauric and myristic acids, showing the best experimental coating. The amount of food grade oleic acid was 14.2% of the wax minus the amounts of lauric and myristic acids used, which are shown.

translucent liquid (with turbidity = 1765 NTU) after two weeks of storage at 20 °C.

Addition of beeswax to the carnauba wax coatings tended to reduce the gloss of coated grapefruit and apples (Table 6). An additional problem with beeswax is the rather low limit set by FDA for its usage with coatings, which would seem to fall under the 'all other' category, for which the limit is 20 ppm (FDA, 21CFR184.1973). Thus, the coating on a typical orange weighing 250 gm could contain only 5 mg beeswax, which is only about 8% of the 60 mg of coating typically applied to an orange (Hagenmaier and Baker, 1994a). Thus, beeswax has somewhat limited potential for use in fruit coatings.

Coated pummelo. Ammonia-based shellac and carnauba wax formulations were both used at two different concentrations as coatings on two types of pummelo, which reacted much differently to application of coatings (Table 7). The weight loss was lower for the candelilla wax, but similar for 10% and 20% formulations of shellac and carnauba wax, demonstrating again that type of coating is much more important than concentration (Hagenmaier and Baker, 1994a).

The internal gas and ethanol concentrations were markedly different for different coatings and also for the two different varieties of pummelo (Table 7, Figs. 7 and 8). The shellac coating at 20% solids would be a very poor choice for

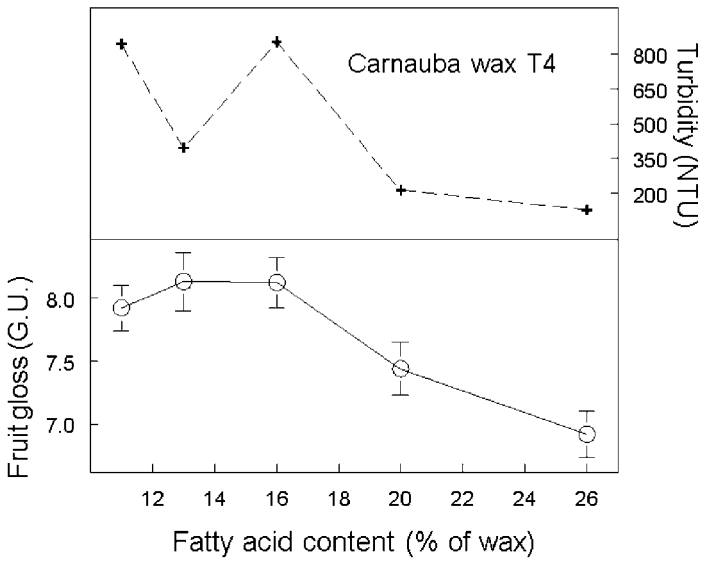

Fig. 4. Mean gloss of grapefruit with wax coatings made from grade T4 carnauba wax, based on 100 readings of G.U. at 60 °C for each coating.

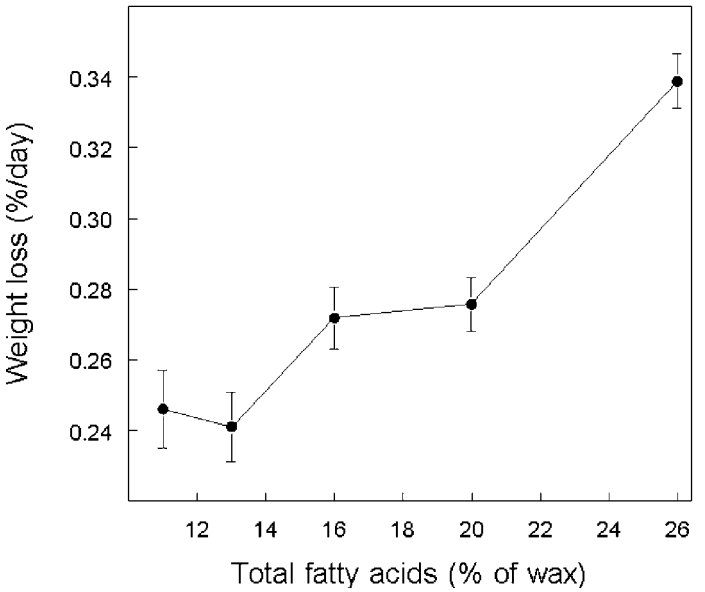

Fig. 6. Weight loss of Red Marsh grapefruit with mean weight of 430 g during 3 days storage at 20 °C, 50% R.H., n = 30.

Table 5. The gloss of Marsh Red grapefruit and Red Delicious apples with coatings made of beeswax and T4 carnauba wax. All were made with 14 g oleic acid and 6 g lauric acid per 100 g wax, using the atmospheric method.

Wax ingredients (g)		Turbidity (NTU)	Gloss (G.U.)[z]	
Carnauba	Beeswax		Grapefruit	Apples
50.0	50.0	194	7.0 b	4.0 c
75.0	25.0	118	6.9 b	4.7 b
77.5	12.5	167	7.6 a	4.5 b
100.0	0.0	158	7.3 ab	5.5 a

[z]Means in a column with different superscript are not the same, $p < 0.05$, LSD.

Table 6. The gloss of Red Delicious Apples with ammonia-based carnauba wax coatings, compared with control and a commercially-available carnauba-wax coating.

Coating	Gloss[z] (G.U.)
Brilliance[y]	6.28 a
T4[x]	5.94 a
Non-coated control	2.09 b

[z]Means with different superscript are not the same, $p < 0.05$, LSD, n = 100
[y]A carnauba-wax coating from CH2O, Inc., Yakima, WA.
[x]Made with 5.6 g food grade oleic acid plus 4.2 g each of lauric and myristic acids, respectively, per 100 g T4 carnauba wax, made with the atmospheric method.

the 'Siamese' pummelo because it resulted in very low internal O_2 and high ethanol, an indicator of off-flavor. The 10% shellac and the 10% candelilla wax coatings also tended to the same result for this variety. By contrast, the carnauba wax coatings at both 10 and 20% total solids resulted in higher internal O_2 and lower ethanol, both desirable. For 'Kao Phuang' pummelo on the other hand, all coatings save 20% shellac kept internal O_2 above 3 kPa and ethanol below 200 ppm.

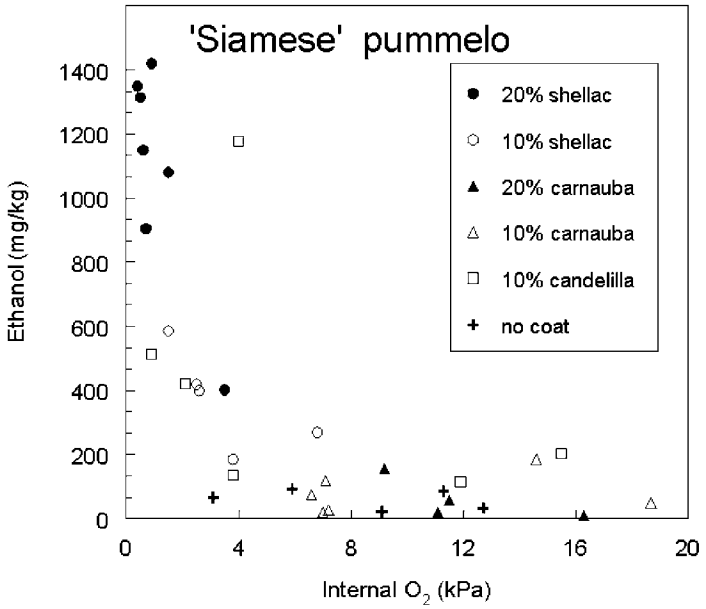

Fig. 7. Ethanol content of 'Siamese' pummelo stored 6 days at 20 °C with different coatings. Internal O_2 and ethanol contents are mean values of two determinations.

In conclusion, careful adjustment of the amount of plasticizer used in rosin coatings has potential to optimize fruit appearance and internal quality. More studies to fine tune the balance of rosin and plasticizers are needed. The gloss of the ammonia-based coatings described herein were about the same as those of commercially-available fruit coatings, all of which contained morpholine. Some beginnings were made to optimize the experimental ammonia-based coatings, only enough to show that morpholine does not appear to be a necessity. It can easily be replaced with ammonia, thus avoiding the concerns some regulatory bodies have had with this ingredient in coatings. Carnauba wax coatings performed well on pummelo fruit, for which no literature data on coating suitability were found.

Table 7. Pummelo coated with shellac and wax coatings of different concentrations, stored 4 days at 20 °C, 60% relative humidity.[z]

Variety	Coating	Weight loss (%)	Internal gas concentrations (kPa)	
			CO_2	O_2
'Kao Phuang'	Carnauba, 20% t.s.	1.5 cd	4.1 b	16.8 s
	Carnauba, 10% t.s.	2.0 c	3.6 b	17.4 s
	Shellac, 20% t.s.	2.0 c	9.7 a	10.3 b
	Shellac, 10% t.s.	2.6 b	8.6 a	11.9 b
	Candelilla, 10% t.s.	1.1 d	5.7 b	15.0 a
	None	4.2 a	3.5 b	17.4 a
'Siamese'	Carnauba, 20% t.s.	1.7 b	9.3 bc	9.8 ab
	Carnauba, 10% t.s.	1.7 b	7.3 c	11.8 a
	Shellac, 20% t.s.	1.9 b	23.8 a	1.2 c
	Shellac, 10% t.s.	1.7 b	14.5 b	2.7 c
	Candelilla, 10% t.s.	0.9 c	10.4 bc	5.6 bc
	None	3.0 a	10.1 bc	8.7 ab

[z]For each variety, means in a column with different superscript are not the same, $p < 0.05$, LSD, n = 100.

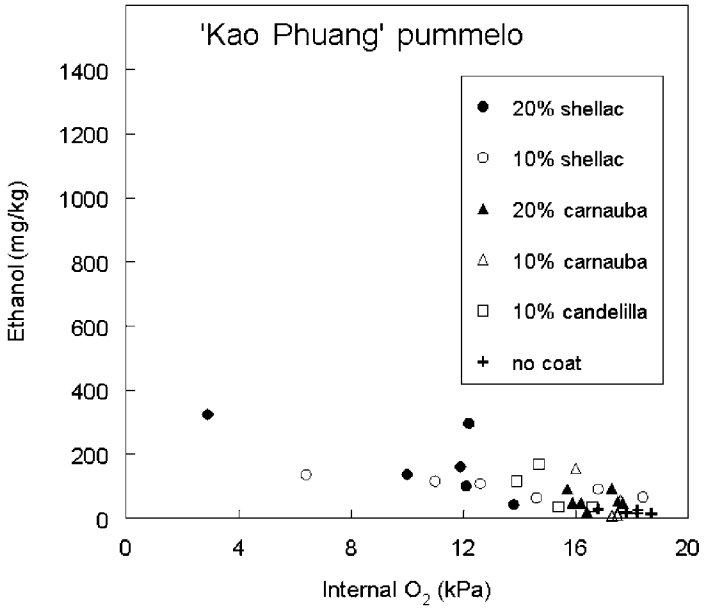

Fig. 8. Ethanol content of 'Kao Phuang' pummelo stored 6 days at 20 °C with different coatings. Internal O_2 and ethanol contents are mean values of two determinations.

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