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EFFECT OF SEVERAL SHINY COATINGS ON THE INTERNAL GASES AND QUALITY OF APPLE FRUIT

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Abstract. **Zein, starch, polyvinyl acetate (PVA), carnauba, and carnauba-polysaccharide (CPS) coatings were applied post controlled atmosphere storage to 'Red Delicious' apples for comparison to a commercial shellac coating. Coated apples were stored in air at 2°C for two weeks and then removed to 21°C for an additional two week simulated marketing period. Gloss, internal gases, weight loss, flesh firmness, sugars and acid content were measured. Starch and carnauba coated apples showed high initial gloss, which were comparable to the shellac coating. Other coatings showed moderate initial gloss. Gloss decreased during storage to similar levels for all coatings after the 4 week experimental period, although all of the coated fruits remained significantly glossier than uncoated controls. For uncoated apples, the difference in internal O_2 and CO_2 concentrations at ambient atmosphere was 1 to 2 percent at 2°C, and increased one more percent after transfer to 21°C. Fruits coated with shellac and starch showed higher than 10 percent internal CO_2, and lower than 10 percent O_2 at 21°C. Zein-, PVA- and carnauba-coated apples showed moderate internal gases (6-7%CO_2, 11-15%O_2). There was an inverse relationship between internal O_2 and CO_2 for most coatings, except for the CPS coating, for which levels of both CO_2 and O_2 were low. Coated fruits exhibited less weight loss than uncoated except for those treated with the CPS coating. The carnauba coating was the most effective water barrier of the coatings tested, but lost this property when the polysaccharide was added. Starch-, shellac-, and CPS-coated fruit were firmer than those from other coating treatments, and all coated fruits were firmer than uncoated controls. Titratable acidity was higher in the fruits coated with CPS, starch, and shellac than in uncoated controls.**

Most 'Red Delicious' apples marketed in the United States are coated with shellac or shellac-carnauba waxes. Shellac is associated with non-food uses, which might some day be viewed negatively by consumers; therefore alternative coatings must be found and provided to the apple industry. Furthermore, shellac is currently not listed as GRAS by FDA.

High gloss is considered by the industry as the primary factor for red apple coatings. Reducing water loss and respiration rate also have benefits for extending post controlled atmosphere (CA) storage life of apples. Respiration rate of apple depends on the storage temperature and atmosphere. Coatings affect the internal atmosphere of fruit and, therefore, decrease the respiration rate. Internal O_2 and CO_2 of uncoated 'Red Delicious' apples at ambient temperature are 17 to 20% and 2 to 4% respectively (Alleyne and Hagenmaier, 2000; Bai et al., 1990). Increasing internal CO_2 and decreasing O_2 levels in coated fruit is expected, due to fruit respiration, resulting in a modified atmosphere (MA) similar to MA packaging. Fruit coated by shellac accumulated CO_2 to about 10%, and reduced O_2 to about 9% at ambient temperature, leading to ethanol accumulation of about 10 times that of uncoated control and other coatings. The gas changes caused by shellac coating were moderated more or less by adding carnauba or candelilla wax to the formulations (Alleyne and Hagenmaier, 2000). Ueda et al. (1993) stored 'Starking Delicious' apple in MA packaging at 8°C, and indicated that the resulting 6% CO_2 in the package caused off-flavor under a moderate O_2 concentration (7-9%). Since the differences of O_2 and CO_2 concentrations between in-fruit and in-package are 1-3% (Bai et al., 1990), then when internal CO_2 levels exceed 7-9%, off-flavor may result.

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In this research, we developed several edible and shiny coatings, and observed how they affected internal gases and subsequently the quality of the coated apples.

Material and Methods

'Red Delicious' apples (*Malus domestica* Borkh.) were stored in commercial CA in Washington state for 4 to 5 months, then transported to Florida in a refrigerated truck in spring, 2000. Uniform (approx. 200 g) defect-free fruits were stored at 5°C for 0 to 2 weeks, then equilibrated at room temperature (25°C) for 24 h, prior to application of coatings. Coatings were applied manually, using 0.5 ml/fruit, spread evenly over the fruit surface using gloved hands. A pilot-plant scale conveyor dryer (Central Florida Sales and Service, Inc., Auburndale, FL) was used to dry fruits at 50°C for 5 min. Fruits were stored at 2°C for 2 weeks, then transferred to 21°C and 45% RH for a further 2 weeks, to simulate marketing conditions.

The treatments included experimental zein-, starch-, polyvinyl acetate (PVA)—and carnauba-polysaccharide (CPS)—based formulations, as well as commercial carnauba- (Natural Shine TM 8000, EcoScience, Orlando, FL), and shellac-based (Apple Wax 55, EcoScience, Orlando, FL) coatings and uncoated controls. The main components of the experimental formulations are: 1) zein (8% defatted zein, 8% propylene glycol, 25% isopropanol, 25% ethanol and 34% water); 2) starch (11.7% potato starch [amylogum CLS, Avebe, Princeton, NJ], 3.1% tapioca dextrin [K4484, National Starch and Chemical Co., Bridgewater, NJ], 3.1% citric acid, 0.8% malic acid, 0.6% whey protein isolate [Bipro, Davisco Foods, Le Sueur, MN], 0.8% glycerin, 10% isopropanal and 70% water); 3) PVA (20% polyvinyl acetate [Union Carbide, Danbury, CT], 2.2% citric acid, 0.8% propylene glycol, 57% isopropanol, and 20% water).

Gloss, internal O_2 and CO_2, weight loss, and flesh firmness were measured with 10 replicate fruits per treatment, while sugar and acid levels were determined using 3 composite replicates of 3 fruit each. Measurements were conducted initially and after the storage and marketing periods.

Fruit surface gloss was measured using a micro-TRI-gloss reflectometer (BYK-Gardner, Silver Spring, MD) equipped with a shield having a circular 19-mm-diameter aperture (Hagenmaier and Baker, 1994), and expressed as gloss units (GU) at an angle of 60°. Ten measurements were applied per fruit. The same fruits were used initially and at the end of the storage and marketing period for gloss measurements.

Flesh firmness was assessed with a penetrometer (FT 327, McCormick, Facchini, Alfonsine, Italy), equipped with an 1 cm^2 cylinder plunger. Two measurements were obtained per fruit from opposite sides where 16-mm-diameter peel discs were removed.

Samples for internal gas were obtained from the core cavity of fruit under submerged conditions (Alleyne and Hagenmaier, 2000). The CO_2 and O_2 concentrations were analyzed using a gas chromatogragh (HP 5890A, Hewlett-Packard, Avondale, PA).

For weight loss determinations, fruits were individually weighed initially and at the end of the storage and marketing periods.

Analysis of sugars was accomplished using a Perkin Elmer Series 410 HPLC system, which separated sucrose, glucose, and fructose for quantification (Bett et al., 2000; Baldwin et al., 1991). Fruit homogenate with equivalent water was kept at -20°C prior to analysis. Defrosted homogenate was added to 80% ethanol, blended for 30 min, and vacuum-filtered through Whatman No 4 filter paper. The resulting extract was passed through a C-18 Sep Pak (Waters/Millipore, *Milford*, MA) and a 0.45-m millipore filter. The filtered extract was analyzed using a Waters Sugar Pak column at 90°C, with a mobile phase of 0.0001 M ethylenediamine-tetraacetic acid disodium-calcium salt (Ca EDTA), flow rate of 0.5 ml·min^{-1}, and a Perkin Elmer LC-25 Refractive Index detector. Sucrose equivalents (SE) were used to show the relative sweetness, with coefficients of sucrose, glucose and fructose as 1, 0.74, and 1.73 respectively (Koehler and Kays, 1991).

For titratable acidity (TA) analysis, homogenates were titrated with NaOH, and calculated as malic acid.

PROC GLM of SAS Version 6.12 (SAS Institute, Cary, NC) was used for analysis of variance.

Result and Discussion

Uncoated fruits showed low gloss with 3.7 gloss units (GU) initially, and decreased to 2.7 GU at the end of the total 4-week experiment (Fig. 1). Shellac-coated fruit showed initial GUs up to 11.3, decreased to 10.1 GU after 2 weeks of storage at 2°C, and further decreased to 7.3 GU in the following 2 week marketing period at 21°C. Since 'Red Delicious' apples with 6 GUs were obviously shiny to the eye, the fruit coated by shellac maintained adequate gloss, even at the end of the marketing period. Starch- and carnauba-coated fruit showed high initial gloss values similar to shellac, while PVA-, zein- and CPS-coated fruit showed moderate initial gloss (7.5-8.8 GU). The gloss of all coatings decreased during holding, but remained higher than the uncoated control. There were minimal differences among the different coating treatments at the end of the experiment (5.9-7.3 GU), since the higher initial gloss coatings lost more shine than those that started at moderate gloss levels (Fig. 1). All the coatings maintained substantial shine after the simulated marketing period.

Internal O_2 and CO_2 concentration in uncoated fruits at the end of 2 weeks storage (2°C) were 20.1 and 1.1%, respectively, and after 2 weeks at 21°C, 18.1 and 2.8%, respectively (Table 1). In coated fruits, more modification of the internal

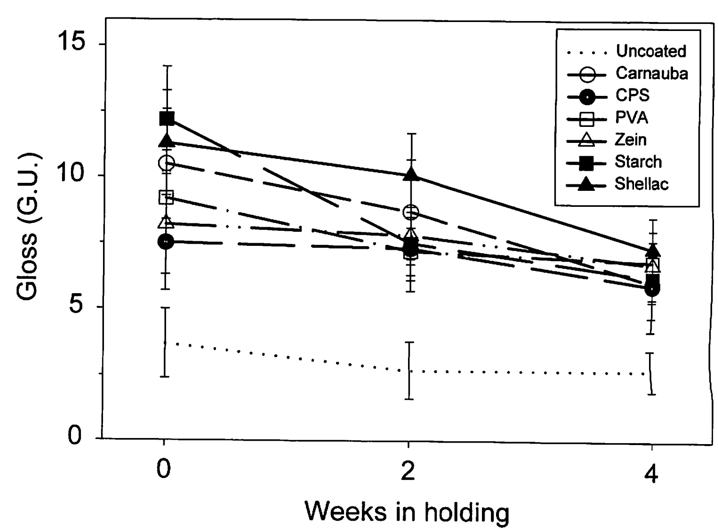

Figure 1. Gloss of apple fruit coated with several types of coating formulations or uncoated during storage at 2°C for 2 weeks followed by 2 weeks at 21°C.

Table 1. Internal O_2 and CO_2 concentrations of 'Red Delicious' apples coated with 6 formulations or uncoated, and held at 2°C for 2 weeks followed by 21°C for 2 weeks[z].

	Week 2		Week 4	
Treatment	O_2 (%)	CO_2 (%)	O_2 (%)	CO_2 (%)
Uncoated	20.1 a[y]	1.1 c	18.1 a	2.8 c
Carnauba	14.8 c	4.6 b	14.5 b	6.3 b
CPS	10.3 d	4.6 b	6.0 d	5.9 b
PVA	17.1 b	3.6 b	11.4 c	7.4 b
Zein	17.7 b	3.6 b	14.6 b	6.5 b
Starch	13.5 c	4.6 b	9.9 c	11.3 a
Shellac	11.8 cd	5.9 a	9.0 c	10.1 a

[z]Initial (week 0) concentrations at 5°C: 20.0% O_2 and 1.8% CO_2.
[y]Mean value (n = 10) in same column that are not followed by the same letter show significant difference ($p < 0.05$).

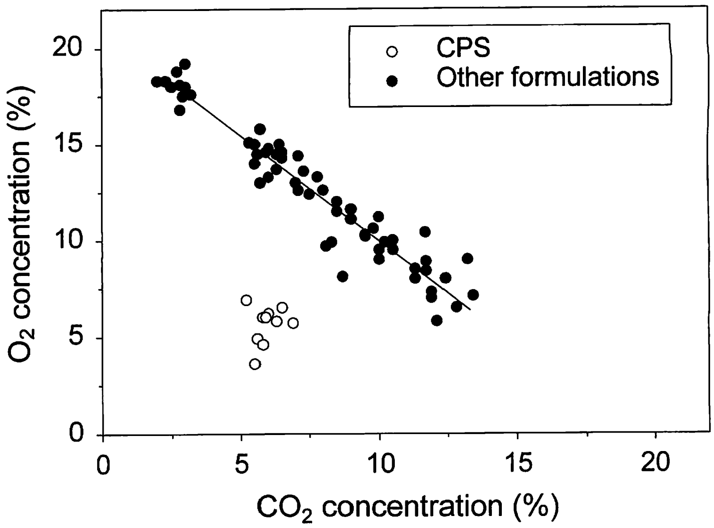

Figure 2. Relationship between internal O_2 and CO_2 of 'Red Delicious' apple fruit coated with several types of coating formulations or uncoated, held for 2 weeks at 2°C followed by 2 weeks at 21°C. The linear regression line is for formulations other than the carnauba-polysaccharide (CPS), with a slope of -1.1 and an intercept of 21.0 ($r^2 = 0.908$).

atmosphere occurred. Internal gas concentrations of fruit coated by shellac were 9.0% O_2 and 10.1% CO_2 at the end of the 4 week experiment. The MA created by the starch coating was similar to shellac. However, zein, PVA and carnauba showed moderate MAs of 11.4 to 14.6% O_2 and 6.3 to 7.4% CO_2. The CPS coating resulted in relatively low values in both of internal O_2 (6.0%) and CO_2 (5.9%).

The recommended CA storage conditions for 'Delicious' apple in the United States are, 1 to 3% O_2 with 0 to 5% CO_2 at 0°C (0-0.5°C for a few states, Thompson, 1996). The CO_2 limit is 5% for most apple cultivars, beyond which injury will occur (Watkins, 2000). Conversely, the O_2 limit is 1.5%, below which anaerobic respiration can occur (Beaudry, 2000). Apple fruit are more sensitive to high CO_2 and low O_2 at ambient temperature than at 0°C since respiration increases with temperature. The high levels of observed CO_2 in shellac and starch coated fruit (10.1 and 11.3%, respectively) would be injurious to the fruit, although the marketing period is relatively short in duration. Zein, PVA, carnauba and CPS coatings resulted in more moderate CO_2 (5.9-7.4%) levels. None of the internal O_2 levels in coated fruit were low enough to cause anaerobic respiration. The CPS coating showed a unique and unusual characteristic; the coated apples had low values of both internal O_2 and CO_2. Normally if oxygen is low, carbon dioxide is high, and vice versa, as the relationship shown on Fig. 2. This means that the CPS coating was more permeable to CO_2 than to O_2. It indicates a possibility of developing optimum coatings for CO_2 sensitive cultivars.

Weight loss of uncoated fruit was 2.1% after 4 weeks of storage (2 weeks at 2°C + 2 weeks at 21°C). The CPS coating was the least effective in inhibiting weight loss (2.2%), while carnauba wax alone was the most effective (1.3%). Other coatings showed intermediate weight loss control (1.7-1.8, Table 2). Weight loss is mainly caused by evaporation of water in fruit. Coating as an additional barrier to the peel inhibited water loss (except for CPS). Water loss can cause shrinkage, softening of the flesh, ripening, senescence through ethylene production and other metabolic changes. Evaporation and diffusion of O_2 and CO_2 through the coatings did not show strong relationships.

Initial firmness of flesh was 6.6 kg cm^{-2}. Firmness decreased slowly at 2°C and faster at 21°C. After the 4 week storage period, the uncoated fruit exhibited 3.8 $kg \cdot cm^{-2}$ firmness (Table 2). All of the coated fruits maintained firmness values of 4.5 $kg \cdot cm^{-2}$ or greater. Generally, the coatings resulted in higher internal CO_2 and/or lower internal O_2 levels (Table 1), and maintained greater firmness values compared to uncoated. A firmness value of 4.5 $kg \cdot cm^{-2}$ is considered the marketable limit for 'Delicious' apples. Fruits with lower firmness values than 4.5 $kg \cdot cm^2$ acquire a mealy texture in 'Delicious' apples.

Coated fruits generally exhibited higher TA than controls, with CPS, starch, and shellac being significantly different (Table 2). Although there were no significant differences in SE, SE/TA showed that all coated fruit had significantly lower values than uncoated controls. The average contents of

Table 2. Weight loss, firmness, sucrose equivalents (SE), titratable acidity (TA) contents and acid-sugars ratio of 'Red delicious' apples coated with 6 formulations or uncoated, and held at 2°C for 2 weeks followed by 21°C for 2 weeks.

Treatment	Weight loss (%)	Firmness (kg/cm^2)	SE	TA (%)	SE/TA × 100
Uncoated	2.1 a[z]	3.8 c	16.7 a	0.18 b	92.8 a
Carnauba	1.3 c	4.7 b	16.5 a	0.20 ab	82.5 b
CPS	2.2 a	5.2 a	16.0 a	0.23 a	69.6 c
PVA	1.7 b	4.7 b	16.2 a	0.19 ab	85.3 b
Zein	1.8 ab	4.5 b	16.5 a	0.20 ab	82.5 b
Starch	1.8 ab	5.6 a	15.9 a	0.24 a	66.2 c
Shellac	1.7 b	5.4 a	15.7 a	0.23 a	68.3 c

[z]Mean value (n = 10 for Weight loss; n = 3 for SE, TA, and SE/TA) in same column that are not followed by the same letter show significant difference ($p < 0.05$).

individual sugars were 7.1% fructose, 3.3% glucose, and 1.4% sucrose, for which there were no significant differences among treatments (data not shown). Hulme and Rhodes (1971) reported that taste in pome fruits is principally based on acid-sugar balance. The ratio of SE/TA indicates that all of the coating treatments delayed ripening and the deterioration of flavor by preventing loss of acitity.

Conclusion

'Red Delicious' apples coated with zein-, starch-, carnauba-, CPS-, and PVA-based formulations showed moderate initial shininess, and ultimately a similar level of gloss compared with those coated with shellac, after storage for two weeks at 2°C followed by two weeks at 21°C. Shellac- and starch-coated fruit showed the greatest deterioration of gloss during storage compared to the other coating treatments, partially due to the fact that they had the highest initial gloss readings. The formulations of zein, carnauba, CPS and PVA provided more optimum internal gas levels, and maintained good quality.

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THE EFFECTS OF HIGH PRESSURE PROCESSING ON SENSORY AND STABILITY OF PRE-CUT MANGOS AND CARAMBOLAS

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Abstract. **Tommy Atkins' mangos were peeled, cubed and vacuum-sealed in flexible retortable pouches. Some portion of the pouches were processed at 300 MPa for 1 minute, others processed at 600 MPa for 1 minute, and the remainder kept as controls. All treatments were stored in the dark at 3°C and evaluated by a trained sensory panel every 1-2 weeks for 9 weeks. Fresh mango flavor declined and off-flavor increased during storage, but color and other sensory attributes changed very little. After 9 weeks of storage, microbial levels in the control were greater than 1×10^4 cfu/mL, ca. 1×10^2 cfu/mL in the 300 MPa treatment, and ca. 1×10^1 cfu/mL in the 600 MPa treatment. Pressure treatments also slightly reduced fresh mango flavor and increased off-flavor and sweetness. 'Arkin' carambolas were sliced and vacuum-sealed in flexible retortable pouches. They were treated at pressures of 600 MPa for 2, 4, or 6 minutes, at 800 MPa for 1, 3, or 5 minutes, and non-treated samples served as controls. All treatments were stored in the dark at 3°C and evaluated at 2 and 4 weeks. Evaluation consisted of exposing the carambolas to air and measuring the color every 2 hours for 8 hours. The 800 MPa pressure treated carambola samples did not brown nearly as much as the non treated samples and 600 MPa treated samples.**

The objectives of this research were to determine the quality and stability of pre-cut mangos and carambolas, and the effects of high pressure treatment on quality and stability.

The mango (*Mangifera indica* L.) is one of the most popular and widespread tropical fruits in the world and has increased in worldwide production by nearly 50% between the years of 1971 and 1993 (Food and Agriculture Organization of the United Nations, 1993). There are over 3000 acres of mango trees in Florida. In 1997 there were 1700 acres of trees that were harvested with an estimated value of $1,450,000. This is the packing house estimate which does not account for mangos that are sold in specialty markets and as green for processing. Therefore the actual value of mangos in the state is much higher than the packing house estimate (Florida Agricultural Statistics Service, 1999).

Mangos are of tropical origin and are sensitive to chilling injury if stored below 10°C, therefore storage at low temperatures results in a short postharvest shelf-life. In a paper by Mc-