Effect of two edible coatings with different permeability characteristics on mango (Mangifera indica L.) ripening during storage

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Abstract

Two types of fruit coatings were tested for their effect on external and 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 exhibited markedly different O2 permeability characteristics under laboratory conditions. This confirmed what has been reported in the literature, that polysaccharide coatings are less permeable to respiratory gases, such as O2, and more permeable to water vapor compared to carnauba wax. When applied to fruit under simulated commercial conditions, however, the difference between the coatings in permeance to respiratory gases were much reduced, most likely due to the high humidity during chilled storage. Both coatings created modified atmospheres, reduced decay, and improved appearance by imparting a subtle shine; but only the polysaccharide coating delayed ripening and increased concentrations of flavor volatiles. The carnauba wax coating significantly reduced water loss compared to uncoated and polysaccharide-coating treatments. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Flavor volatiles; Modified atmosphere; Ethylene; Carbon dioxide; Oxygen; Permeance; Sensory

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1. Introduction

Mango is one of the most favored specialty fruits in the US (Vance Publications, 1994) and is very popular world-wide (Koulibaly et al., 1992; Mitra and Baldwin, 1997). Mango fruit (*Mangifera indica* L.) are climacteric and ripen rapidly after harvest. Disease susceptibility, sensitivity to low storage temperatures (below 13°C), and perishability due to ripening and softening limit the storage, handling and transport potential of the fruit (Mitra and Baldwin, 1997). Mango fruit are harvested commercially within a range of maturities including immature green (dark green, no shoulders, ripens with poor quality), mature green (lighter green, shoulders formed, ripens with acceptable quality) and tree ripe (fruit that show color breaking to red or orange-yellow, ripen with optimum quality) (Bender et al., 1995; Mitra and Baldwin, 1997). External and internal quality is critical to consumer acceptability, and flavor is an important marketing consideration (Gholap et al., 1986).

Some extension of shelf life has been demonstrated using controlled atmosphere (CA) storage (relatively low O2 and high CO2) (Bender et al., 1997). However, CO2 injury, increased ethanol production, and flavor problems due to anaerobic respiration have been reported (Lakshminarayana and Subramanyam, 1970; Bender et al., 1994). Concentration of flavor volatiles and/or flavor quality were affected by harvest maturity, CA (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 and water loss, and reduce decay (McGuire and Hallman, 1995; Baldwin et al., 1997), but may also alter flavor (Cohen et al., 1990; Hagenmaier and Baker, 1993). Semi-permeable coatings can create a modified atmosphere (MA) (Nisperos-Carriedo et al., 1990; Baldwin et al., 1995) similar to CA storage, with less expense incurred. However, the atmosphere created by coatings can change in response to environmental conditions, such as temperature and humidity, due to combined effects on fruit respiration and coating permeability (McHugh and Krochta, 1994; Baldwin et al., 1995). 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 for CA storage. Furthermore, use of coatings can entrap aroma volatile compounds, thereby increasing their concentrations (Nisperos-Carriedo et al., 1990; Baldwin et al., 1995).

Given the perishability of mango and its importance in world agricultural commerce, we initiated a study to determine the effects of two types of commercial coatings on mango fruit quality under simulated commercial conditions. Few coatings are currently used on mango fruit in the US, and two were selected because they have been used commercially and reportedly differed in permeability characteristics, which could affect important factors such as ripening, flavor, and weight loss.

2. Materials and methods

2.1. Fruit attributes

Mango fruit (*M. indica* L. cv Tommy Atkins) were purchased from a commercial mango distributor based in Homestead, FL, USA in 1996 and 1998. The fruit represented a typical range of maturities that would be found in a packinghouse operation (immature green to tree ripe) and had been subjected to quarantine treatment (46°C: 90 min hot water) prior to entering the US from Mexico. Fruit were selected for uniformity in size (0.35–0.45 kg), and freedom from defects while immature green fruit were discarded. Fruit were divided into three groups for three treatments such that each treatment contained the same range in maturity (mature green and tree ripe) based on ground color (Bender et al., 1995).

For headspace and internal gas analysis in 1996, each of 12 fruit per treatment were placed in individual 1.75-l glass jars (total of 36 jars) and held in a flow-through system of humidified air (99% RH, 1.67 l h⁻¹). The fruit were stored at 15°C for 19 days after which they were removed to 20°C in a non-humidified air flow-through
system (56% RH) for 4 days to simulate marketing conditions. Headspace gases were sampled from the exit tube of each jar in the flow-through system and analyzed for ethylene, CO₂ and O₂ by gas chromatography (GC) (Bender et al., 1994). The fruit respiratory gases were allowed to stabilize at the storage temperature–humidity conditions and come into an approximate equilibrium with the flow-through system for the first 5 days. Headspace O₂ and CO₂ concentrations in the jars were calculated from the difference between the inlet (air) and outlet (headspace gas) concentrations and expressed in terms of g fruit fresh weight.

An approximation of the internal gas under the peel was determined for fruit in the flow-through jars using a surface diffusion technique. Each fruit was equipped with 30 mm rubber sleeve stopper (Wheaton Scientific, Millville, NJ, USA) sealed to the fruit surface with caulking material and secured with rubber bands. The seal integrity was tested with positive pressure. A 6 ml volume under the stopper headspace was sampled for internal gas analysis after allowing at least 4 days for an equilibration of the sealed area with the internal atmosphere of the fruit in a method similar to that demonstrated by Saltveit (1993), Petracek (1995), and McGuire (1997). A 0.5 ml sample from the stopper headspace samples was taken every 4 to 6 days during chilled storage and another sample 4 days after placement of the fruit at 20°C. Ethylene determinations were made using a photoionization GC, Photovac 10A10 (Thornhill, Ontario, Canada), equipped with an activated alumina column. Respiratory gases (CO₂ and O₂) were analyzed on a Gow-Mac Series 580 GC (Bridgewater, NJ, USA) with Porapak Q and molecular sieve columns and a thermal conductivity detector (Bender et al., 1994). Data were corrected for argon (0.93% of air) which is not separated from O₂ by the above method.

For weight loss determinations, an additional ten fruit per treatment in the first group were held in large glass jars at the same storage temperatures (15 and 20°C) and humidity levels (99% and 56%) as described above. Each fruit was weighed at the beginning and at the end of the experiment to determine total weight loss during the combined chilled and marketing storage periods. Observations of appearance and surface texture were made after coating application and drying, after removal from chilled storage, and during simulated commercial storage at 20°C.

For volatile analysis, the first group of fruit (12 plus 10 fruit/treatment for gas and weight loss, respectively = 22 fruit/treatment) were individually analyzed after chilled storage plus 4 days at 20°C. Fruit pulp (150 g) from each fruit was homogenized with an equal amount of water, flash frozen in liquid nitrogen and stored at −5°C prior to analysis. Volatile compounds were analyzed as peak heights or quantified by adapting headspace analysis procedures developed previously for citrus (Nisperos-Carriedo and Shaw, 1990) and tomato (Baldwin et al., 1991) and modified for mango (Malundo et al., 1997). Thirteen aroma volatiles were measured including acetaldehyde, acetone, methanol, ethanol, α-pinene, caryophyllene, 3-carene, β-pinene, myrcene, limonene, terpinolene, α-copaene, and ρ-cymene. The first four compounds are shown as peak heights. Standard curves for the rest were run by spiking bland mango homogenate (majority of volatiles distilled off using a roto-evaporator, Malundo et al., 1997) with authentic standards at five different levels for each compound (µl l⁻¹): α-pinene, 1.5-60.0; caryophyllene, 0.3-6.0; 3-carene, 14.0-140.0; β-pinene, 0.1-4.0; myrcene, 0.5-20.0; limonene, 0.15-6.0; terpinolene, 0.32-13.0; α-copaene, 0.12-1.20; and ρ-cymene, 0.04-0.40. Analysis was conducted using a Perkin-Elmer GC (Model 8500) with a HS-6 headspace sampler (Perkin Elmer, Norwalk, CT, USA), polar Stabilwax column (Restek, Bellefonte, PA, USA) and flame ionization detector. Concentrations were calculated by regression equations to obtain a peak height calibration curve as described previously (Nisperos-Carriedo et al., 1990; Malundo et al., 1997).

Analysis of soluble solids (SS) of 22 fruit/treatment after storage was done in fruit homogenates by refractometer, titratable acidity (TA) by titration with NaOH (Jones and Scott, 1984), and initial pH using a pH meter. The data for SS and TA are expressed as percent g fresh weight.
All 22 fruit/treatment were checked for decay symptoms at the end of the experiment (+/− decay). The decayed fruit were expressed as percentage of total.

In a subsequent experiment (1998), fruit were selected for the same maturity range, treated with the same coatings and stored at 10°C and 90–95% RH for 17 days followed by 20°C and 56% RH for 3 days in boxes (three boxes of six fruit each or 18 fruit/treatment) in storage rooms. Internal gases were monitored during storage on three additional fruit per treatment (with serum stoppers attached) and sensory analysis, weight loss, firmness and decay determinations were done at the end of the experiment on all fruit (21 fruit/treatment total). For sensory tests, samples of fruit pulp (1 cm³ cube each of three fruit/treatment) were presented in random order to 16 panelists under red light and rated on a 9-point hedonic scale for sweetness, sourness, off-flavor and overall flavor, with intensity or acceptability increasing with numerical value.

Firmness was determined at the end of the storage period using an Instron Model 1011 (Instron Corporation, Canton, MA, USA) by recording the force necessary to compress the fruit 2 mm using a rounded 1 cm diameter probe.

2.2. Treatments

Fruit were coated with either a cellulose-based polysaccharide coating, Nature Seal® 2020 (NS), a carnauba wax coating, Tropical Fruit Coating 213 (TFC) obtained from EcoScience (Orlando, FL, USA) or not coated (controls). The NS formulation was composed of hydroxypropylcellulose at 5% plus preservative, acidulant and emulsifiers for a total solids of 7%. The TFC formulation contained 5% carnauba wax and fatty acid soaps for a total solids content of 10.8%. Coatings were applied by hand with a sponge and the fruit were air-dried with a fan.

To determine coating permeability, both coatings were each spread on polyethylene film in the laboratory to form films of mean 8 μm thickness (four replications/coating type). Thickness was determined as surface density of the coating (mg cm⁻²) divided by specific gravity (1.37 for dried NS, 0.97 for TFC). Oxygen permeance of the coated and uncoated polyethylene film was determined at 30°C, 60% RH with Ox-Tran 100 (Modern Controls, Minneapolis, MN, USA). Oxygen permeance of the coating was calculated from steady state gas flux as:

\[ \frac{1}{\text{permeance of coating}} = \frac{1}{\text{permeance of coated film}} - \frac{1}{\text{permeance uncoated film}}. \]

Oxygen permeability of coatings on polyethylene film was then calculated as thickness × permeance (Hagenmaier and Shaw, 1991, 1992). For the coated mangoes, thicknesses of coatings were not known and, therefore, permeability could not be calculated. In this case, permeance of the coated peel was calculated from the gas flow rate, headspace and internal gas concentrations as:

\[ \text{flux} = \text{ml (m}^2 \text{s Pa)}^{-1} \times \text{permeance} = \frac{[\text{mol gas (s flux}^{-1})]/[\text{Area (m}^2))}{\Delta P (\text{Pa})} \]

This should be considered as an ‘apparent’ permeance, since flux of gases through the peel of the fruit, whether coated or not, can occur by permeance or by diffusion through open spaces, such as stomata, stem scar, lenticels, (Hagenmaier and Baker, 1993) and mass flow (possible microwind erected by pressure imbalances).

2.3. Statistical analysis

The data were analyzed using the Statistical Analysis System (SAS, 1998). Analysis of variance (PROC ANOVA) or the general linear model (PROC GLM) were used to determine effect of treatment on dependent variables at each sampling time during storage (permeance and levels of gases) and at the end of storage for quality factors (weight loss, SS, TA, pH and volatiles). Means were separated by least significant difference (LSD) or Duncan’s multiple range at \( P < 0.05 \). The regression procedure (PROC REG) was used to determine effect of storage time on permeance and levels of gases for each treatment.
3. Results and discussion

Although the two coatings used in this study showed similar permeances during simulated commercial storage, these were different enough to result in some variation in quality characteristics in the stored fruit.

3.1. Appearance, texture, weight loss and decay

Beneficial effects of fruit coatings include improvement of appearance and reduction of weight loss. Both coating treatments imparted an attractive natural-looking sheen to the fruit. The coating, TFC, had a slightly waxy feel while NS felt smooth and dry after application and subsequent drying. After removal from cold storage, the fruit became wet with condensation which solubilized the hydrophilic NS coating, giving it a temporarily slippery texture that returned to normal after re-drying. Condensation appeared to have no effect on the texture of the hydrophobic TFC coating. At the end of the storage period for the first experiment, TFC-coated fruit stored in glass jars showed less weight loss than those in the other treatments (Table 1), while there was no significant difference between NS-treated and control fruit. In the second experiment, with fruit stored in cartons, weight loss was greater due to the lower storage RH, NS-coated fruit lost significantly less weight than controls, and TFC-coated fruit had the lowest weight loss (Table 1). Carnauba wax is relatively hydrophobic and presents a good barrier to moisture loss, whereas polysaccharide coatings are hydrophilic, and thus generally have higher permeability to water vapor (Hagenmaier and Shaw, 1992; Hagenmaier and Baker, 1993). McGuire and Hallman (1995) reported similar results with these two coatings applied to guava fruits stored at 12°C and ambient humidity.

Decay was identified as general, stem-end-rot (SER) or as anthracnose (Colletotrichum gloeosporioides). SER occurs as dark brown lesions typically at the stem-end and is caused by several fungi (Johnson, 1994), but was most likely Phomopsis mangiferae. Anthracnose appears as black spots and streaks (Snowdon, 1990). Coating treatments appeared to help reduce postharvest decay. The first symptoms of decay were observed after 3 days at 20°C. At the end of the first experiment, 6% of NS-coated fruit in glass jars showed symptoms of SER and less than 1% with anthracnose (total = 7%). Fruit treated with TFC had no SER and <1% of the fruit developed anthracnose. In comparison, 45% and 14% of control fruit exhibited SER and anthracnose, respectively, at the end of the experiment (total = 59%). In the second experiment, for fruit in cartons, 24% of both NS- and TFC-coated fruit showed general decay versus 38% of uncoated controls (Table 1). It is possible that for mango the coatings presented a physical barrier to pathogen development in contrast to what was observed for guava fruit treated with similar coatings (McGuire and Hallman, 1995).

<table>
<thead>
<tr>
<th>% Weight loss (g FW)</th>
<th>% Decay</th>
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<tbody>
<tr>
<td><strong>Storage in glass jars</strong></td>
<td><strong>Storage in boxes</strong></td>
</tr>
<tr>
<td>NS</td>
<td>1.8 a</td>
</tr>
<tr>
<td>TFC</td>
<td>1.4 b</td>
</tr>
<tr>
<td>CONTROL</td>
<td>1.9 a</td>
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* Data are means of ten fruit/treatment, values within a column with the same letter are not significantly different (P≤0.05).
* Data are means of 21 fruit/treatment, values within a column with the same letter are not significantly different (P≤0.05).
* Data are percentage decayed of 22 fruit/treatment.
* Data are percentage decayed of 21 fruit/treatment.
3.2. Sugars, acids, and firmness

The NS-treated fruit ripened more slowly as indicated by higher acidity and firmness. The SS values were similar (14.5–15.2%) in fruit from all treatments at the end of the storage period of the first experiment, while the pH was significantly lower and TA significantly higher in fruit coated with NS compared to those in the other two treatments (Fig. 1). Higher TA and lower pH in NS-coated fruit could also be the result of formation of carboxylic acid by dark fixation of CO$_2$ (Pesis and Ben-Arie, 1986) due to high internal CO$_2$ levels (Fig. 3). The second experiment yielded similar results for SS (14.0–16.5%), lower values for TA, and higher values for pH (but relatively similar differences among treatments), with NS- and TFC-coated fruit showing lower pH than uncoated controls (pH 4.6, 4.7 and 5.5, respectively, for NS, TFC and uncoated) with the reverse for TA (0.28, 0.21, and 0.16, respectively, for NS, TFC and uncoated). The means for pH were significantly lower for coated fruit (Duncan’s test, $P \leq 0.001$). The means for TA were significantly higher for NS-, but not TFC-coated fruit compared to controls ($P \leq 0.02$). Firmness was determined at the end of storage in the second experiment with NS-coated fruit being the most firm, requiring 7.0 N to compress 2 mm, followed by TFC (5.3 N) and uncoated controls (2.8 N). All three means for compression force were significantly different from each other (Duncan’s test, $P \leq 0.05$). McGuire and Hallman (1995) reported that these same coatings delayed ripening of guava stored at 12°C and ambient humidity, with NS being more effective than TFC.

3.3. Aroma volatiles

Nine of the 13 aroma volatiles measured at the end of the first experiment were found at higher concentrations in fruit coated with NS compared to the other two treatments (Fig. 2A–C); including acetaldehyde, acetone, ethanol, α-pinene, 3-carene, β-pinene, myrcene, limonene, and terpinolene. Levels of methanol were significantly higher in TFC-coated fruit compared to NS-coated or controls (Fig. 2A) and caryophyllene was higher in TFC-coated fruit compared to NS-coated (Fig. 2B), while there were no significant differences for α-copaene or ρ-cymene (Fig. 2C). Otherwise, fruit coated with TFC exhibited similar levels of volatile compounds to control fruit. NS-coated fruit had 66-fold higher ethanol and
7-fold higher acetaldehyde compared to uncoated fruit and eight times more ethanol and four times more acetaldehyde compared to TFC-coated fruit (Fig. 2A). This indicates that anaerobic respiration was taking place in NS-coated fruit, but levels of ethanol and acetaldehyde were accumulating along with other volatiles that are not normally associated with anaerobic respiration. It appears that the NS coating was less permeable to these volatiles than the TFC coating, thus their levels were building up within the coating barrier. The increased levels of ethanol in NS-coated fruit, therefore, may have been partly due to increased ethanol production (anaerobic respiration) and also to restricted diffusion out of the fruit. Methanol levels found in the mango homogenate may have come from the action of pectin-methyllyesterase in demethylating cell wall pectin upon homogenization as has been suggested for citrus (Nisperos-Carriedo and Shaw, 1990) and tomato (Baldwin et al., 1999).

3.4. Sensory evaluation

Scores for sweetness were between 6.1 and 6.3 for all treatments in the second experiment, reflecting the similar values for SS among the treatments. Scores for sourness were 4.2, 3.2, and 3.0 for NS-coated, TFC-coated and uncoated fruit, respectively, reflecting the higher TA and lower pH for NS-coated fruit. Scores for overall flavor were 5.1, 4.8, and 5.4 for NS, TFC and uncoated fruit; and 4.5, 4.1, and 3.7 for NS, TFC, and control fruit for off-flavors. Only sourness was significant ($P \leq 0.0001$), with NS fruit being perceived as more sour, although there was a trend toward higher scores for off-flavor for NS-treated fruit, which may have been related to the

![Fig. 2. Peak height or concentration (μl 1⁻¹) of volatile compounds: (A) acetaldehyde (ACETALD), acetone (ACETONE), methanol (MEOH), ethanol (ETOH); (B) α-pinene (α-PINENE), caryophyllene (CARY), 3-carene (CAR); (C) β-pinene (β-PINENE), myrcene (MYRC), limonene (LIM), terpinolene (TERP), α-copaene (COP), and ρ-cymene (CYM) from headspace of mango homogenate from fruit stored 19 days at 15°C, 99% RH plus 4 days at 20°C, 56% RH, coated NS, TFC or not coated (CONT). Data are means of 22 fruit/treatment with mean separation by LSD ($P \leq 0.05$). Bars with the same letter are not significantly different for each compound.](image-url)
high levels of ethanol and other volatiles. Nevertheless, there was no significant difference in overall flavor among the treatments.

3.5. Coating permeability/permeance to oxygen

The two coatings differed markedly and significantly \((P \leq 0.0001)\) in oxygen permeability under laboratory conditions of 30°C and 60% RH. The NS and TFC coatings allowed passage of \(1.9 \pm 0.4 \times 10^{-5}\) and \(52 \pm 4.0 \times 10^{-5}\) pmol m \((m^2 s Pa)^{-1}\) of \(O_2\), respectively, which are mean values from four replicate samples. Permeability is a combination of Ficks's first law of diffusion and Henry's law of solubility. These laws are used to express steady state permeability of a permeate through a nonporous barrier of a certain thickness (Donhowe and Fennema, 1994). Thus, at 60% RH, NS had relatively low \(O_2\) permeability, while the TFC coating had a comparatively high value, about half that of polyethylene film. Under higher RHs, less difference in \(O_2\) permeability would be expected, however, since water vapor acts like a plasticizer and increases permeability of films in general, and of hydrophilic films like NS in particular (Kester and Fennema, 1986). Nevertheless, these data support previous laboratory reports that carnauba wax is much more permeable to gases including \(CO_2\) and \(O_2\) (Hagenmaier and Shaw, 1992; Baldwin et al., 1997) compared to cellulose (the film base in NS) or shellac. Oxygen permeability is an important characteristic for fruit coatings. If the permeability is too low, anaerobic respiration will commence, resulting in a build-up of acetaldehyde, ethanol and off-flavors as well as product deterioration. If coating permeability is too high, the internal atmosphere will not be modified sufficiently to result in a beneficial reduction of ethylene synthesis and delayed ripening (Baldwin, 1994).

Permeance is the permeability expression without accounting for thickness and is used for performance evaluation (Donhowe and Fennema, 1994) under conditions where an equilibrium is reached in reference to gas concentrations on either side of a coating. In this case permeance values were estimated to reflect the comparative performance of coatings on fruit under simulated commercial storage conditions and with the possible interaction of coatings with the fruit surface. True equilibrium of gases on either side of the coating/fruit peel barrier could never be reached since the fruit were ripening, and thus internal and headspace gases were slowly changing over time. This is because ripening mango undergo changes in production of \(CO_2\) and ethylene and consumption of \(O_2\). There would be some delay before these changes in internal atmosphere reached the area under the rubber stopper or the headspace, but the atmosphere in the stopper should reflect what is under the peel.

Throughout the storage period of the first experiment, both coating treatments generally exhibited less permeance to \(O_2\) than control fruit, but overall there was little difference between the two coating treatments (Fig. 3A). Generally, permeance of coatings and mango peel alone (controls) to \(O_2\) decreased over the chilled storage period, significant for all treatments \((P \leq 0.02)\). It would be expected that coating permeance would change after removal from chilled storage/high humidity after day 19, due to the change in temperature and RH. Higher temperatures can slightly increase permeability, while a decrease in RH would be expected to have the opposite effect. In any case, \(O_2\) permeance increased for the NS coating resulting in a significant difference compared to TFC on day 22 (Fig. 3A). This is in contrast to the \(O_2\) permeability data under laboratory conditions (30°C, 60% RH) discussed above, and might be explained by the possible differences in coating ability to plug stomata and to adhere to the fruit cuticle. In addition, the effect of high humidity, and of condensed water on coating permeability, was probably more significant for the hydrophilic NS formulation than for the hydrophobic TFC.

We expected to see a modified atmosphere for coated fruits consisting of relatively lower \(O_2\) and higher \(CO_2\) levels compared to controls due to the combined effect of coating permeability and fruit respiration. We also anticipated that the contributions of respiration to the modified atmosphere to be somewhat repressed during chilled storage and that coating permeability would be increased by the high humidity. Nevertheless, internal \(O_2\) con-
centrations were significantly lower for coated fruit compared to controls throughout the storage period of the first experiment (Fig. 3B). The effect of high humidity on coating permeance, however, minimized the difference in modified atmospheres between the two types of coatings. Polysaccharide-based coatings, such as NS, are reported to be less permeable to O$_2$ (as described above) and CO$_2$ than the carnauba wax formulations represented by TFC (Hagenmaier and Shaw, 1992). However, the coating/peel permeance to O$_2$ decreased during storage more for the NS-coated than for TFC-coated fruit, which is reflected in significantly lower internal O$_2$ on days 13 and 19 (Fig. 3B). After removal from chilled storage, internal O$_2$ levels then increased in NS-treated fruit, reflecting increased permeance, and were significantly higher than for TFC-coated fruit (Fig. 3A and B). Generally, levels of internal O$_2$ significantly declined over storage time ($P \leq 0.001$) but the decline was greater for control fruit.

### 3.6. Coating permeance to carbon dioxide

In contrast to O$_2$ permeance data, the NS coating showed a trend toward lower permeance values for CO$_2$ at each sampling time in the first experiment compared to TFC, but these differences were not significant (Fig. 3C) at any sampling time. Also, CO$_2$ permeance decreased more gradually for coated fruit (significant only for the NS treatment) and more rapidly for controls, especially after removal from chilled storage/high
RH to ambient conditions ($P \leq 0.04$). Both coatings exhibited lower permeance to CO$_2$ than controls throughout the storage period. The fact that O$_2$ permeance seemed to be more affected by the storage conditions (which included high RH) than CO$_2$ does not reflect the solubility of these two gases in water. O$_2$ is less soluble in water than CO$_2$ (Budavari et al., 1996). After removing the fruit from chilled, high RH storage, O$_2$ permeance increased while CO$_2$ decreased in NS-coated fruit (Fig. 3A and C). Upon removal from chilled storage, the fruit became wet with condensate, which temporarily solubilized the hydrophilic NS coating and may have altered its permeability.

Both coating treatments resulted in higher internal CO$_2$ levels compared to uncoated control fruit in the first experiment (Fig. 3D) during the storage period. This presumably reflects the consistently lower permeance values for CO$_2$ for NS- and TFC-treated fruit (Fig. 3C). Nevertheless, there was only one sampling day (day 22), under conditions of lower RH and higher temperature, when treatment of fruit with NS resulted in significantly higher ($P \leq 0.001$) internal CO$_2$ concentrations compared to TFC (Fig. 3D). The levels of internal CO$_2$ changed significantly over time ($P \leq 0.001$) and increased for all treatments after placement at 20°C (day 22). This may be indicative of rapid ripening, which had been repressed during chilled storage.

3.7. Coating permeance to ethylene

The permeance values for ethylene could not be reliably calculated due to low and variable levels of ethylene in the first experiment. There were no significant differences between treatments for internal ethylene levels (data not shown). However, internal ethylene increased significantly in all treatments after removal from chilled storage (0.64 to 8.09, 0.23 to 6.65, and 1.10 to 8.46 nl ml$^{-1}$ for NS, TFC, and uncoated controls, respectively, at $P \leq 0.05$) as did internal CO$_2$, and may reflect rapid ripening.

In the second experiment there were less differences in internal gas concentrations due to the lower storage temperature (10°C), but coated fruit were generally lower in O$_2$ and higher in CO$_2$ compared to uncoated controls. There were no significant differences between coating treatments at most sampling times during chilled storage, and TFC-coated fruit were again lower in O$_2$ compared to NS after 3 days at 21°C (data not shown).

4. Conclusion

In conclusion, coating mango fruit reduced decay and the TFC coating also reduced weight loss, confirming a previous report for reduced weight loss of guavas (McGuire and Hallman, 1995). Soluble solids were similar in all treatments, TA was significantly higher in NS-coated fruit compared to fruit from the other treatments, and NS-treated fruit were firmer than the other treatments, indicating a delay in ripening and/or accumulation of carboxylic acids. Overall, shelf life was extended by coating treatments due to delayed ripening and softening, reduced decay and weight loss. NS-coated fruit also exhibited substantially higher levels of ethanol and eight other volatiles out of the 13 aroma compounds analyzed at the end of the storage period. Thus, NS-coated fruit may have had altered flavor compared to TFC-coated or uncoated fruit. However, in the second experiment there were no significant differences for sensory evaluation of off- or overall-flavor among the three treatments. NS was less permeable to O$_2$ than TFC under conditions of low RH in the laboratory. Under storage conditions of low temperature and high humidity, however, the two coatings displayed roughly similar permeances when applied on mango fruit for CO$_2$ and O$_2$, and similar internal gas concentrations for CO$_2$ and ethylene, while internal O$_2$ levels were sometimes different. This indicates that the permeance of the NS coating was more affected by high RH during chilled storage and condensate after removal from chilled storage than TFC, probably due to its hydrophilic nature. The higher CO$_2$, acetaldehyde and ethanol levels may have contributed to a greater delay in ripening for NS fruit since these compounds are reported to have an effect on this process via retardation of ethylene synthesis and action (Kader, 1986;
Saltveit and Mencarelli, 1988; Beaulieu et al., 1997; Kelly and Saltveit, 1998).

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