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Coating selection for 'Delicious' and other apples☆

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Abstract

The gas permeabilities of shellac and several experimental coating formulations, including candelilla wax and shellac-carnauba were measured. These coatings, selected to have a wide range of gas permeabilities, were applied to freshly harvested and 5-month commercially stored 'Delicious', 'Fuji', 'Braeburn' and 'Granny Smith' apples. The coated apples were monitored during storage of 2 or 4 weeks at 20 °C for changes in internal gases level, and for quality parameters (surface gloss, weight loss, flesh firmness, Brix, titratable acidity and ethanol content). The shellac coating resulted in maximum fruit gloss, lowest internal O_2, highest CO_2, and least loss of flesh firmness for all of the varieties. The 'Granny Smith' with shellac had low internal O_2 (< 2 kPa) with both freshly harvested and 5 month-stored apples, and the freshly-harvested 'Braeburn' had high internal CO_2 (25 kPa). This excessive modification of internal gas induced an abrupt rise of the respiratory quotient, prodigious accumulation of ethanol in both 'Braeburn' and 'Granny Smith', and flesh browning at the blossom end of 'Braeburn'. In addition the shellac coating gave an unusual accumulation of ethanol in freshly harvested and 5 month-stored 'Fuji'. Candelilla and carnauba-shellac coatings maintained more optimal internal O_2 and CO_2 and better quality for 'Fuji', 'Braeburn' and 'Granny Smith' apples, although even these coatings may present too much of a gas barrier for 'Granny Smith'. Therefore, this research recommends the best coatings as shellac for 'Delicious', and carnauba-shellac for 'Braeburn' or 'Fuji'. Best for 'Granny Smith' would seem to be a high-permeability wax similar to polyethylene, which has not been approved for apple by FDA. In general, the gas permeabilities of the coatings were useful as an indicator of differences in coating barrier properties, but did not account for differences in pore blockage.

Keywords: Coating; Apple; Internal gas; Variety; Ethanol

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1. Introduction

Coating apples prior to marketing is standard practice in the United States. 'Delicious' has been a key apple variety in the apple coating development, and this cultivar is relatively tolerant to high gas barriers. Thus, apple coatings have tended to emphasize improvement of visual gloss with little need for other effects on the fruit that might result from a high barrier to gas exchange (Baldwin, 1994; Saftner et al., 1998). A shellac coating seems an excellent fit for dark red 'Delicious' apples; because it imparts high gloss, hides bruises and forms a modified atmosphere condition that tends to preserve firmness and prolong shelf-life for this variety (Alleyne and Hagenmaier, 2000; Bai et al., 2002).

When fruit is separated by a barrier, such as a coating or packaging, from exchange of gases with the atmosphere, there is the possibility for respiration to become anaerobic with the associated development of off-flavor. Coatings and packaging developed for one type of fruit may not be suitable for another.

More recently, apple varieties with different physiological sensitivity to internal O_2 and CO_2 levels and different colors have tended to replace 'Delicious'. These varieties may also differ from 'Delicious' in the porosity of the peel and the structure of blossom- and stem-ends, and thus the same coating may result in a different modified internal atmosphere and physiological reactions to a given internal gas composition. These considerations suggest determining if coatings developed for 'Delicious' are optimum for other varieties. In addition, consumer preference for more 'natural' products might lead to less preference for high-gloss coatings.

For this study, we selected five coating treatments with a wide range of barriers to gas exchange, from non-coated control to shellac, a strong barrier coating. One of the intermediate coatings was made mostly of candelilla wax, which is considered a GRAS substance, that is, allowed by the FDA with no limitations other than good manufacturing practice (CFR, 184.1976; FDA, 1999). Apples with candelilla wax coatings have a nearly natural, non-coated appearance (preliminary experiments). Another coating with intermediate permeability was a 50–50 mixture of a shellac solution and a carnauba wax microemulsion. Both materials are commonly used in apple coatings. Finally, we also selected polyethylene wax for comparison due to its extremely high permeability to gases. This material is permitted by FDA as a coating for many other fruits and vegetables, but not for apples.

2. Materials and methods

Freshly harvested, non-coated, Washington apples were obtained on 25 October, 2000 from Publix Supermarket after having been shipped to Florida in refrigerated trucks. These were stored at 3 °C in air until 10 November, then washed and experimental coatings were applied with gloved hands (Bai et al., 2002). Mean fruit weights were 197, 204, 222 and 201 g for 'Delicious', 'Fuji', 'Braeburn' and 'Granny Smith' apples, respectively.

Apples that had been stored 5 months following harvest by Yakima Fruit and Cold Storage Co. (Yakima, WA) were obtained from the same source 15 March and coated 20 March. The 'Delicious' were stored in controlled atmosphere (CA) at 1.8 kPa O_2,1.8 kPa CO_2, and 1 °C. The 'Fuji' were stored in CA at 8 kPa O_2, 2 kPa CO_2, and 1 °C. The 'Braeburn' were stored at about 3 °C in air and the 'Granny Smith' in CA at 2 kPa O_2, 1.7 kPa CO_2, and 1 °C. The mean weights of these fruits were 235, 247, 247 and 231 g for 'Delicious', 'Fuji', 'Braeburn' and 'Granny Smith', respectively.

Our laboratory formulated the experimental coatings as follows: Polyethylene: 18.6% oxidized polyethylene (AC680 from Allied Signal, Inc., Morristown, NJ), 3.4% food-grade oleic acid (Emersol 6321, Henkel, Cincinnati, OH), 2.8% morpholine, 0.01% polydimethylsiloxane antifoam (SE21, Wacker Silicones Co., Adrian, MI), with the balance being water (true for all formulations tested).

Candelilla: 18.3% candelilla wax (SP 75, Strahl & Pitsch, Inc., West Babylon, NY), 2.1% oleic acid, 2.4% morpholine, 0.02% polydimethylsiloxane antifoam.

Carnauba-shellac: 9.5% shellac (R52, Mantrose Haeuser Co., Attleboro, MA), 8.3% carnauba wax (No. 1, Strahl & Pitsch, Inc.), 3.3% morpholine, 1.7% oleic acid, 0.17% NH_3, 0.01% polydimethylsiloxane antifoam.

Shellac: 19% shellac, 1.0% oleic acid, 4.4% morpholine, 0.3% NH_3, 0.01% polydimethylsiloxane antifoam.

Shellac-WPI: 13.3% shellac, 3.0% whey protein isolate (BiPRO, Davisco Foods International, Inc., Le Sueur, MN), 3.1% morpholine, 0.7% oleic acid, 0.2% NH_3, 0.01% polydimethylsiloxane antifoam.

To determine coating permeability, a polyethylene film was used as a carrier. Approximately 0.5-ml of each coating solution was deposited on the carrier film (ca. 100 cm^2) and was spread evenly with an elastic plough blade. The film was dried for 2–4 weeks at 50% RH and 23 °C. Film thickness was measured using a caliper micrometer (Model XLI 20000, Federal Products Co., Providence, RI) taking measurements at six locations on the film and averaging the result. The thickness of the films ranged from 8 to 40 μm depending on coatings. Carbon dioxide and oxygen permeances of the coated and uncoated polyethylene was determined at 30 °C, 60% RH with a permeation test system (Ox-Tran 100, Modern Controls, Minneapolis, MN). The permeability was calculated by dividing the oxygen or CO_2 transmission rate by the gas partial pressure and multiplying by the film thickness (Hagenmaier and Shaw, 1991, 1992). Three to eight replicates were applied for every formulation.

For coating application, 1.0 ml per fruit aliquots of the coating were spread evenly over the fruit surface using latex-gloved hands. The effective amount of applied material was 0.6 g per apple. Instead of coating, water was used for control fruit. A pilot-plant scale conveyor dryer (Central Florida Sales and Service, Inc., Auburndale, FL) was used to dry fruit (including controls) at 50 °C for 5 min (Bai et al., 2002). After application of coatings the apples were stored at 20 °C and approximately 70% relative humidity for 4 weeks.

Gloss, weight loss, and flesh firmness were measured on 20 individual fruit per treatment. Internal O_2, CO_2 and ethylene were determined using ten individual fruit for each treatment. Measurements were conducted initially, and following storage for 2 and 4 weeks at 20 °C. Initial measurements were taken 1 day after coating, to allow the fruit to recover from the hot air drying process, and to allow coatings to completely dry. For 5 month-stored ‘Delicious’, ‘Braeburn’, and ‘Granny Smith’ apples, apparent softening (too soft to measure firmness using a penetrometer) and/or internal browning occurred after 2 weeks. Therefore, there are no measurement for the 4 weeks storage period.

Gloss was measured using a reflectometer (model micro-TRI-gloss, 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 made per fruit. The same fruit were used initially and during storage.

Flesh firmness was assessed with a penetrometer (FT 327, Effegi, Alfonsine, Italy), equipped with a cylindrical plunger 11 mm in diameter. Two measurements were obtained per fruit from opposite sides where 16 mm-diameter peel discs were removed.

Samples for internal gas measurement were obtained from the seed cavity of fruit under submerged conditions (Alleyne and Hagenmaier, 2000). The CO_2 and O_2 partial pressures were analyzed using a gas chromatograph (Model 5890A, Hewlett–Packard Co., Avondale, PA) with a thermal conductivity detector. The column was model CTR 1 (Alltech Associates, Inc., Deerfield, IL), which consists of a 3-mm diameter inner polymer column for CO_2 and a concentric 4 mm molecular sieve outer column. This column gives separate peaks for CO_2 and O_2. The CO_2 and O_2 concentrations of samples were determined by peak areas, compared with areas of known standards, except that O_2 content of the samples was not corrected for argon content, about 0.9 kPa in air). Column temperature and flow velocity were 40 °C and 3.0 cm s^{-1}, respectively. The ethylene concentration was analyzed by a gas chromatography, (Model 8500, Perkin–Elmer Co., Norwalk, CT) equipped with a activated alumina column and a flame ionization detector.

Content of titratable acidity, Brix, and ethanol were determined using three composite replicates of six fruit for each treatment.

For titratable acidity (TA) analysis, homogenates were titrated to pH 8.1 with 0.1N NaOH, and the acidity was calculated as malic acid on fresh weight basis (g/100 g) (Jones and Scott, 1984). For weight loss determination, fruit were individually weighed initially and at week 2 and 4.

Brix was measured using a digital, temperature-compensated refractometer (model PR-101, Atago Co., Tokyo, Japan) with freshly prepared juice.

For ethanol content analysis, pulp homogenized with NaCl solution (Bai et al., 2002) were prepared in sealed glass vials, and stored at −80 °C until analysis. For GC analysis, sample vials were thawed under running tap water, heated rapidly to 80 °C and incubated for 15 min by a headspace sampler heating block (HS-6, Perkin–Elmer Co.) before the sample headspace was injected into the GC. The analysis was carried out using a gas chromatograph (Model 8500, Perkin–Elmer Co.) equipped with a 0.53 mm × 30 m polar stabilwax capillary column (1.0-μm film thickness, Restek Co., Bellefonte, PA) and a flame ionization detector. Oven temperature was held at 40 °C for 6 min, then raised to 180 °C at a rate of 6 °C min^{-1} (Bai et al., 2002).

Fruit surface area was calculated according to:

$$A\ (\mathrm{cm}^2) = \alpha \times W^{2/3} \quad (1)$$

where W is fruit mass (g) and α is a coefficient of 5.4, 5.1, 5.0 and 5.2 for ‘Delicious’, ‘Fuji’, ‘Braeburn’ and ‘Granny Smith’, respectively. The coefficient was estimated based on the geometric shape of a sphere (Gaffney and Baird, 1985; Hamilton, 1929; Magness et al., 1926).

For pore flux, a syringe needle was inserted into the apple so that the tip was in the seed cavity, air pressure of about 0.07 kPa was applied, and rate of air going into the apple was measured by observing change in water level of a manometer for 3 min.

The data were analyzed using the Statistical Analysis System (SAS Version 8, SAS Institute, Cary, NC). The general linear model (PROC GLM) was used for analysis of variance. Mean separation was determined by the Scheffe’s test (SAS Institute, 1999).

3. Results and discussion

The coatings used for these experiments had a wide range of gas permeabilities (Fig. 1). Generally, if the CO_2 permeability was high for a coating, so was the O_2 permeability, although the latter was always lower, as is common for most polymers (Comyn, 1985; Hagenmaier and Shaw, 1992; Stannett, 1985).

Generally, the internal O_2 levels fell and the internal CO_2 increased with decreasing coating permeability (Table 1). Nevertheless, the candelilla wax coating, which had lower permeability than the carnauba-shellac coating (Fig. 1), resulted in generally higher values of internal O_2 and lower CO_2. We can speculate that the carnauba-shellac coating had more tendency to block pores in the fruit skin than did the candelilla coating, but have insufficient evidence to conclude that was the case.

The biggest difference between internal gases of freshly-harvested and 5-month stored apples was the internal CO_2 of shellac-coated ‘Braeburn’ (Table 1), which was singularly high (25 kPa) for freshly harvested (but not the stored) apples, in conjunction with flesh browning of approximately 10% of the fruit, usually starting at the blossom-end (Fig. 2), and extended over whole fruit. Others have observed browning of ‘Braeburn’ subjected to high CO_2 (Elgar et al., 1998; Lau, 1998). It is possible that high CO_2 occurred only in freshly harvested, but not 5 month-stored ‘Braeburn’, because the former was going through the climacteric rise of respiration.

The lowest values of internal O_2 occurred in freshly harvested ‘Granny Smith’ apples coated with shellac (1.8 kPa) or carnauba-shellac (1.5 kPa) coating, in 5 month-stored ‘Granny Smith’ with shellac coating (1.9 kPa), and in freshly harvested ‘Braeburn’ (2.1 kPa) with shellac coatings. Note, however, that these O_2 partial pressures included argon (about 0.9 kPa in ambient atmosphere). In all cases these low values of

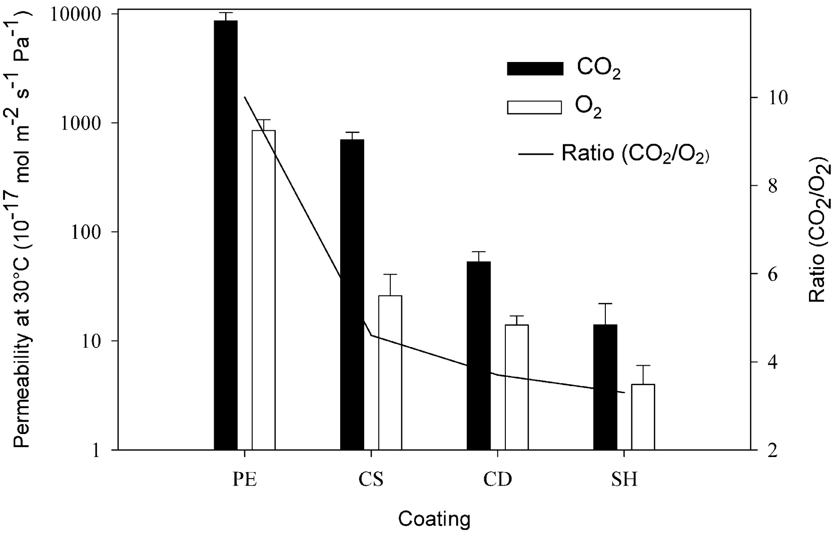


Fig. 1. Coating permeability to CO_2 and O_2. For coating treatments, PE, polyethylene; CD, Candelilla; CS, carnauba-shellac; and SH, shellac.

internal O_2 corresponded with increasing respiratory quotients ([CO_2 production]/[O_2 consumption], data not shown). The substantial accumulation of ethanol (Fig. 3) suggests that these samples had internal O_2 values below the so-called lower oxygen limits (LOL) for aerobic respiration (Beaudry, 1993; Yearsley et al., 1996), which are the internal oxygen concentrations below which ethanol tends to accumulate.

The sum of internal CO_2 and O_2 partial pressures ($P_{CO_2}{}^{i}+P_{O_2}{}^{i}$) was <22 kPa except for freshly harvested 'Braeburn' with shellac coating, which suffered from flesh browning at the blossom end and had internal CO_2 higher than 25 kPa

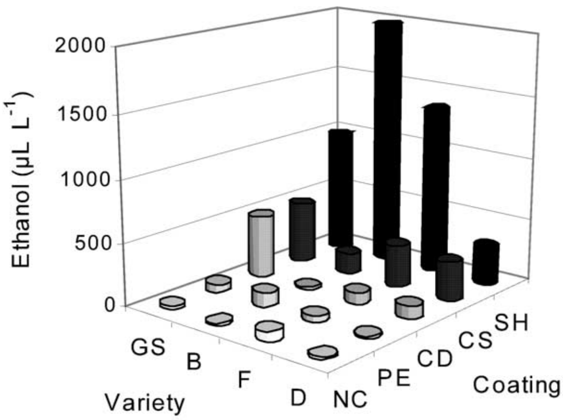
Table 1
Internal CO_2 and O_2 (kPa) of apples stored 14 days at 20 °C after application of different coatings

Coating	Delicious		Fuji		Braeburn		Granny Smith	
	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2
Freshly harvested								
Non-coated	3.4 c[y]	18.1 a	3.1 c	17.7 a	2.8 d	18.0 a	4.1 c	15.8 a
Polythylene	5.9 bc	12.5 b	7.1 b	10.0 b	7.8 c	12.1 b	5.5 c	6.7 b
Candelilla	7.0 b	11.9 b	9.8 ab	9.5 b	10.6 bc	7.1 c	10.2 b	3.6 bc
Carnauba-Shellac	11.2 a	5.5 c	10.7 ab	3.8 c	12.2 b	3.1 d	11.9 b	1.5 c
Shellac	9.6 ab	5.8 c	14.0 a	4.6 c	25.2 a	2.1 d	15.6 a	1.8 c
5-month stored								
Non-coated	2.4 c	18.2 a	2.8 c	18.0 a	2.9 d	18.0 a	5.3 c	11.2 a
Polythylene	6.0 b	13.5 b	6.0 b	14.2 b	6.8 c	13.0 b	6.5 c	4.8 b
Candelilla	9.1 ab	11.1 b	7.5 b	12.8 b	8.5 bc	12.6 b	9.2 b	3.2 bc
Carnauba-Shellac	9.4 ab	9.4 bc	10.9 ab	7.7 c	10.7 b	8.3 bc	10.6 b	3.2 bc
Shellac	11.1 a	6.5 c	12.5 a	5.9 c	13.5 a	6.3 a	19.4 a	1.9 c

The apples were coated when freshly harvested or after commercial storage for 5 months z. z, Apples stored for 5 months before coating were in controlled atmosphere except for 'Braeburn'.

[y] Mean values ($n=10$) in same variety and pre-storage history with the same letter are not different ($P<0.05$).

Fig. 2. Flesh browning of 'Braeburn' at the blossom end showed in longitudinal section. The injury occurred in 10% of the shellac coated fruit.



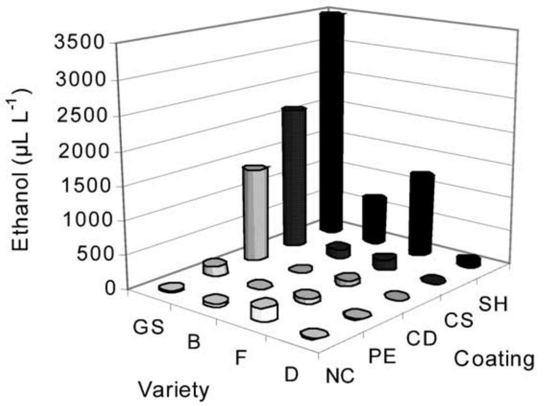


Fig. 3. Ethanol content of apples stored 14 days at 20 °C after application of different coatings. The apples were coated when freshly harvested (upper) or after 5 months storage (bottom). For coating treatments, NC, non-coated; PE, polyethylene; CD, Candelilla; CS, carnauba-shellac; and SH, shellac. For variety, D, 'Delicious'; F, 'Fuji'; B, 'Braeburn'; GS, 'Granny Smith'.

(Table 1, Figs. 2 and 4). Generally one would expect values of ($P_{CO_2}{}^{i}+P_{O_2}{}^{i}$) to be about 21 kPa when gas exchange was diffusion through pores, but lower as permeability becomes more important (Bai et al., 2002; Banks et al., 1993; Yearsley et al., 1996). Note that 'Granny Smith' had lowest values of ($P_{CO_2}{}^{i}+P_{O_2}{}^{i}$) and also relatively few pores (Fig. 5). However, ($P_{CO_2}{}^{i}+P_{O_2}{}^{i}$) did not seem a reliable indicator of ethanol accumulation.

The ratio of pressure differences across the skin, $\Delta P_{CO_2}/\Delta P_{O_2}$ ranges from about 0.4–1.0 except for fruit with excessive internal CO_2 (Table 1, Fig. 4). The ratio tended to be lower for coated than non-coated fruit, suggesting their gas exchange is more by permeability than diffusion through pores (Fig. 4). The exception was non-coated, 5-month-stored 'Granny Smith', which had relatively few pores (Fig. 5). The mean ratio was only about 0.7 for the polyethylene and carnauba-shellac coatings, suggesting that these tended to block pores. The lowest ratio (0.4) was for 'Granny Smith' coated with polyethylene coating (Fig. 4).

If all gas exchange were by permeance rather than by diffusion through pores and other openings, then, from the definition of permeance, the gas flux would have been:

$$\text{Flux (mol m}^{-2}\text{ s}^{-1}) = \text{Permeance (mol m}^{-2}\text{ s}^{-1}\text{ Pa}^{-1}) \times \Delta P\text{ (Pa)} \quad (2)$$

where the ΔP is the difference of internal and external gas partial pressure. The 'resistance' that a barrier offers to permeating gases is defined as 1/Permeance, which is a convenient concept because the resistance of layered barriers is equal to the sum of the resistance of the individual layers. Thus:

$$\text{Resistance to permeance} = \frac{\Delta P}{\text{Flux}}\text{ (Pa s m}^{2}\text{ mol}^{-1}) \quad (3)$$

The resistance was calculated in two ways. The first calculation (the x axis in Fig. 6) was resistance to permeance, calculated as if the apple skin consisted only of a sealed bag made of coating (without holes). The second calculation (y axis)

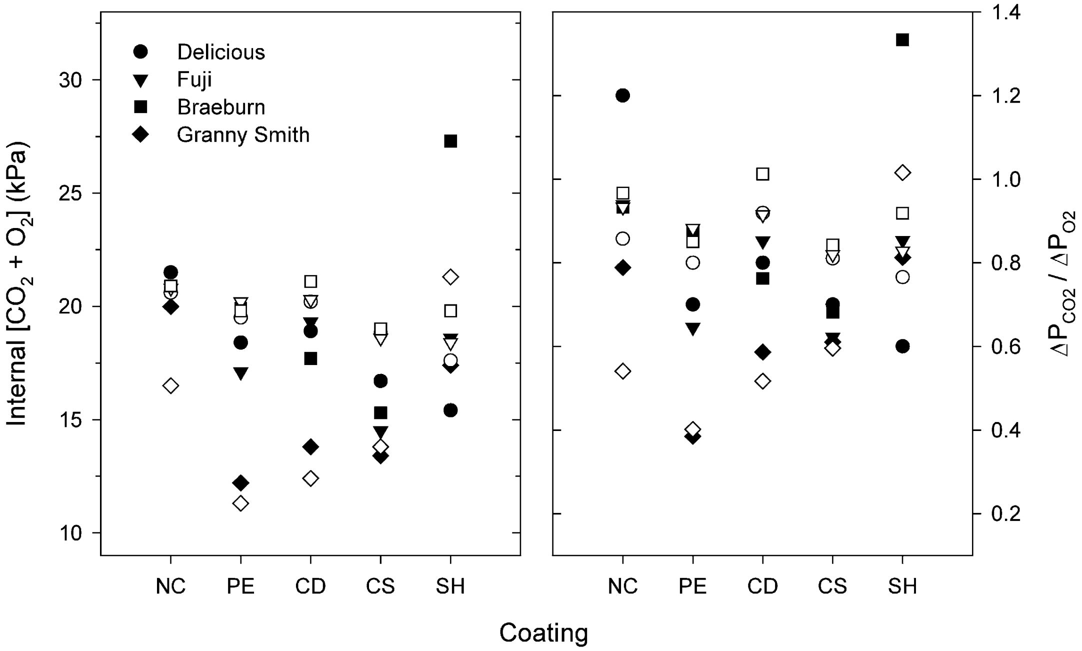


Fig. 4. Sum of internal CO_2 and O_2 (left), and ratio of differences between internal and external CO_2 and O_2 (right) in coated and non-coated apple from four varieties. Freshly harvested (filled symbols) and 5-month stored fruit (open symbols) were coated then held 2 weeks at 20 °C. For coating treatments, NC, non-coated; PE, polyethylene; CD, Candelilla; CS, carnauba-shellac; and SH, shellac.

was an 'apparent resistance to permeance' calculated from Eq. (2) using observed values of internal gas, respiratory flux and fruit surface area. The results (Fig. 6) show little relationship between the two calculations, and thus coating permeance is not useful for calculation of internal

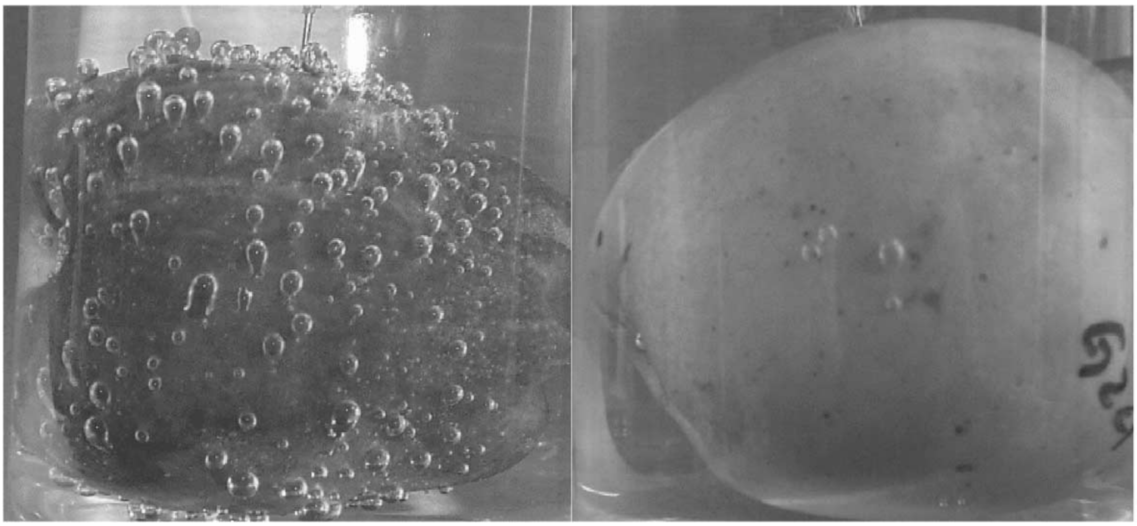


Fig. 5. Bubbles emitted from apple submerged in water when given 0.2 atm pressure of air pushed through the seed cavity for 'Delicious' (left) and 'Granny Smith' (right) apples.

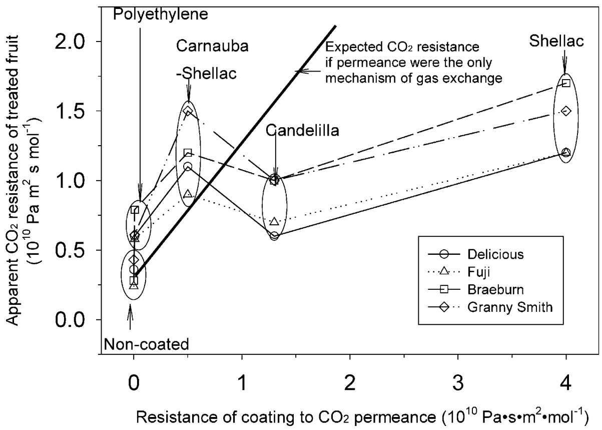


Fig. 6. CO_2 resistance of coated fruit and that of a hypothetical sphere of same size sealed in intact coating.

gases, presumably because much of the CO_2 and O_2 passes through pores and other openings in the skin, such as open lenticels, stem scar, blossom end, and cracks.

Passage of gases through holes in the skin was confirmed by the fact that mean air flux through the non-coated apples entering through the seed cavity was about 7 ml·min^{-1} at 0.07 atm pressure. When the same fruit was submerged in water, only a small percentage of the bubbles caused by exiting air came from the stem and blossom ends, with most originating, instead, on the sides of the fruit (presumably open lenticels; Fig. 5). Fig. 5 also demonstrates the difference in peel anatomy (percentage of open pores) between 'Delicious' and 'Granny Smith', which can affect coating performance.

There was a high risk of excessive ethanol accumulation in 'Granny Smith' apples with any of the coatings containing shellac and candelilla wax (Fig. 3). These fruits had internal O_2 levels of 3.6 kPa or less (Table 1). Freshly harvested 'Braeburn' had 2.1 kPa internal O_2+25.2 kPa internal CO_2 and high ethanol with the shellac coating. 'Fuji' had 4.6–5.9 kPa internal O_2 with shellac coating, which induced ethanol accumulation (Fig. 3). By comparison, Yearsley et al. (1997) reported the LOL at 0–28 °C for 'Cox's Orange Pippin' and 'Braeburn' apple was 1.5–2.0 kPa. The higher LOL in this research may be due to varietal differences, the presence of high partial pressures for CO_2, and longer duration in anaerobic conditions.

Weight loss was least for fruit with candelilla wax coatings (Table 2). The carnauba-shellac coating did not protect against weight loss better than shellac, probably because it contained such a high percentage of shellac, although carnauba wax coatings generally offer good protection (Bai et al., 2002). Only the non-coated 'Fuji' apples lost 5% of initial weight, which is considered enough to induce shriveling (Hatfield and Knee, 1988), although this depends somewhat on variety, orchard, and harvest date (Maguire et al., 2000).

The loss of firmness during storage was least for fruit with coatings that had the most effect on the internal atmosphere (Table 2). This delay in softening may be related to a delay in ripening caused by the modified atmosphere. The firmness of freshly harvested 'Braeburn', 'Fuji' and 'Granny Smith' was maintained for the duration of the experiment (4 weeks). The firmness of 'Delicious', however, declined to less than 44 N, which can indicate onset of mealiness (Bai et al., 2002; Ueda et al., 1993). The change of firmness in different varieties and coatings in 5 month-stored fruit was similar to that of freshly harvested ones.

There were no significant differences in titratable acidity and Brix among the coatings for all of the varieties (data not shown), possibly because of the relatively brief storage time. This is somewhat unexpected. Apples with inhibited respiration generally maintain organic acid levels better during storage than fruit with uninhibited respiration rates. For instance, 1-MCP application to preclimacteric apples prevents climacteric respiration and strongly inhibits loss of titratable acidity during storage without significant effect on Brix (Baritelle et al., 2001). In addition, fruits exposed to anaerobic conditions often accumulate succinic acid (Kader, 1995).

The shellac-coated apples had the highest gloss, and all coated apples had higher gloss than non-coated (Table 2). Other varieties had higher initial gloss than 'Delicious'. As an alternative coating, with less gloss, candelilla may satisfy customers with a 'natural' preference.

Table 2
Glosss, weight loss, and firmness of freshly harvested apples coated with different formulations after 28 °C

Variety	Coating	Gloss (GU)[z]	Weight loss (%)	Firmness (N)
Delicious	Non-coated	2.9 d[y]	3.5 a	37 c (73)[x]
	Polyethylene	7.0 b	2.9 b	37 c
	Candelilla	6.2 c	1.7 e	42 abc
	Carnauba-Shellac	8.3 c	2.2 d	43 ab
	Shellac	8.2 a	2.3 cd	47 a
Fuji	Non-coated	4.1 d	5.1 a	65 b (76)
	Polyethylene	7.9 b	3.7 b	68 ab
	Candelilla	6.9 c	2.1 c	69 ab
	Carnauba-Shellac	8.9 a	3.4 b	73 ab
	Shellac	8.3 ab	3.3 b	74 a
Braeburn	Non-coated	4.7 c	3.3 a	52 b (72)
	Polyethylene	8.9 a	2.6 b	54 b
	Candelilla	7.0 b	1.5 d	54 b
	Carnauba-Shellac	9.0 a	2.2 c	58 ab
	Shellac	9.0 a	2.3 bc	61 a
Granny Smith	Non-coated	5.9 c	3.0 a	55 c (78)
	Polyethylene	10.9 a	2.7 b	57 c
	Candelilla	8.5 b	1.1 d	60 bc
	Carnauba-Shellac	10.1 a	1.8 c	73 a
	Shellac	10.9 a	2.1 c	68 ab

[z] Gloss was measured prior to storage.
[y] Mean values in same column for each variety not followed by the same letter are different ($P < 0.05$) ($n = 100$ for gloss; $n = 20$ for weight loss and firmness).
[x] Values in parentheses are initial firmness of each variety.

4. Conclusion

The polyethylene coating formed the lowest barrier for water vapor loss and the least resistance to CO_2 and O_2 exchange, as indicated by the relatively weight loss, high values of internal O_2 and low internal CO_2, with no delay in softening. Thus, coatings with high permeability do not provide a sufficient barrier to gas exchange and water loss, except possibly for CA-stored ‘Granny Smith’.

For ‘Fuji’ and ‘Braeburn’, the optimum coatings seem to be those with intermediate permeability, like the candelilla or carnauba-shellac. These avoided excessive build-up of ethanol, but helped somewhat to preserve firmness and protect against weight loss.

The ‘Delicious’ apples, especially those from CA storage, seemed to do well with shellac coating, which gave the most change in internal atmosphere without causing excessive ethanol production, and maintained firmness compared with other coating treatments.

The best variety-coating combinations were ‘Delicious’-shellac, ‘Braeburn’ and ‘Fuji’-carnauba-shellac, and ‘Granny Smith’-polyethylene-like coating. Note, however, that polyethylene wax has not been approved for apple by FDA.

In general, the performance of coatings on apples was related to their O_2 and CO_2 permeabilities, with higher permeability resulting in lower internal CO_2 any higher internal O_2. However, this trend was reversed for two of the coatings, presumably because of differences in the ability of these coatings (carnauba-shellac and candelilla) to block pores in the fruit peel.

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