Effects of Temperature and Coating Treatment on Gas Exchange of 'Braeburn' Apples

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Abstract

Achieving modified atmosphere (MA) effects on fruit through the use of surface coatings relies upon a suitable degree of internal atmosphere modification, which is strongly dependent upon both respiration rate and skin permeance to gases. In this study, skin porosity, skin permeance, internal partial pressures of oxygen and carbon dioxide, and respiration rate were measured at 0°C, 10°C, 20°C and 30°C in non-coated 'Braeburn' apples. Variation in respiration rate, internal partial pressures of oxygen and carbon dioxide, skin permeance to oxygen and carbon dioxide, and the extent to which all of these gas exchange characteristics affected by temperatures of 0°C, 5°C, 10°C, 15°C, 20°C were characterised in both non-coated and coated 'Braeburn' apples. Coating treatments were 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times either a 2% (w/w) solution of hydroxypropylcellulose (HPC) in distilled water, or a commercial formulation of carnauba wax and shellac coating, achieved by mixing the full strength solutions with distilled water.

There was a 6- or 10-fold difference in respiration rate between fruit kept at 0°C and 20°C, or 0°C and 30°C, whilst the relative permeance to both O_2 and CO_2 differed only a factor of 1.7 or 1.5 in non-coated fruit. The differing effects of temperature upon these two variables were responsible for the depression of internal O_2 and elevation of internal CO_2 associated with increase in temperature from 0°C to 20°C or 30°C. There was no evidence that porosity was dependent on temperature, suggesting that the increasing permeance with higher temperatures may have resulted from increasing permeance of the cuticle. The modification of internal atmosphere composition in carnauba-coated fruit depended upon coating concentration and temperature. The effects of HPC coating on internal atmosphere, especially on internal CO_2 were less marked than those of temperature.

In non-coated fruit, the magnitude of decline in internal O_2 was slightly greater than the increase in internal CO_2 over the temperature range in the experiment. For apples that were respiring aerobically, this indicates that the fruit skin had a slightly higher permeance to CO_2 than to O_2. Since O_2 diffuses through pores were readily than CO_2, gas exchange of these fruit appeared not to be pore dominated. The suppression of gas exchange by shellac coating was consistent with the coating blocking pores on the fruit surface to an extent that depended on coating concentration. The less pronounced effects of HPC coating in both skin permeance and internal gases were consistent with a coating that loosely covered the fruit surface rather than blocking the pores. Low concentrations of shellac coating achieved low internal O_2 levels at higher temperatures but had only slight effects on internal atmosphere composition at low temperatures. Higher concentrations that achieved MA benefit at low temperatures resulted in fermentation at higher temperatures. Given the natural variability in skin permeance, and the exacerbating effects of coating treatment and temperature, surface coatings appear unlikely to provide a reliable and safe means of achieving modified atmosphere benefits in 'Braeburn' apples.

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List of symbols and abbreviations

$-a$ = parameter representing proportional rate of decline in total gas pressure (s^{-1})

A = surface area of fruit (m^2)

CA = controlled-atmosphere

CO_2 = carbon dioxide

$D_{j,k}$ = diffusion constant of *j* in medium *k*

Δp_j = difference in partial pressure of gas j between internal and external atmospheres (Pa)

Δp^0 = total initial pressure difference between internal and external atmospheres (Pa)

Δp^{tot} = total pressure difference between internal and external atmospheres at time *t* (Pa).

Δx = film thickness (m)

K = parameter representing coefficient of the equation.

K_m = parameter analagous to a Michaelis-Menten constant (Pa)

M = fruit mass (kg)

n = absolute amount of gas in a given sample (mol)

O_2 = oxygen

p^{tot} = total pressure in the external atmosphere (Pa)

p_j^i = partial pressure of gas *j* in the internal atmosphere (Pa)

p_j^e = partial pressure of gas *j* in the external atmosphere (Pa)

$p_{CO_2}^i$ = partial pressure of CO_2 in the internal atmosphere (Pa)

$p_{O_2}^i$ = partial pressure of O_2 in the internal atmosphere (Pa)

P = permeability (mol s^{-1} m m^{-2} Pa^{-1})

P_j = permeability to gas *j* (mol s^{-1} m m^{-2} Pa^{-1})

P_j' = permeance to gas *j* (mol s^{-1} m^{-2} Pa^{-1})

$P_j^{'fruit}$ = skin permeance of fruit to gas *j* (mol $s^{-1}m^{-2}$ Pa^{-1})

$P_j^{',comb.}$ = combined permeance of skin and coating to gas *j* (mol $s^{-1}m^{-2}$ Pa^{-1})

$P_j^{',coat}$ = permeance of a coating barrier (mol $s^{-1}m^{-2}$ Pa^{-1})

P_{CO_2}' = permeance to CO_2 (mol $s^{-1}m^{-2}$ Pa^{-1})

P_{O_2}' = permeance to O_2 (mol $s^{-1}m^{-2}$ Pa^{-1})

$\overline{P}^{skin}$ = porosity of the fruit skin (mol s^{-1} m^{-2} Pa^{-1})

Q_{10} = temperature quotient for respiration

R = gas constant (8.3134 m^3 Pa mol^{-1} K^{-1})

R^2 = square of the correlation coefficient (*r*), or proportion of the total variability in the *y*-values that van be accounted for by the independent variable *x*.

r_j = specific rate of transfer of gas *j* between internal and external atmospheres (mol kg^{-1} s^{-1})

r_{CO_2} = specific rate of transfer of CO_2 between internal and external atmospheres (mol $kg^{-1}s^{-1}$)

$r_{O_2}^{T}$ = respiration rate at T°C (mol kg^{-1} s^{-1})

$r_{O_2}^{max,0}$ = r_{O_2} at 0°C when oxygen is non-limiting (mol kg^{-1} s^{-1})

$r_{O_2}^{max,T}$ = inherent maximum r_{O_2} at T°C when oxygen is non-limiting (mol kg^{-1} s^{-1})

RH = relative humidity

$RQ^{\propto}$ = respiratory quotient when O_2 is non-limiting.

$S_{j,k}$ = solubility coefficient of *j* in medium *k* (mol m^{-3} Pa^{-1})

t = time (s)

T = temperature (°C)

V^a = added gas volume before injection (m^3)

V^i = volume of internal atmosphere within the fruit (m^3)