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

A thesis presented in partial fulfilment
of the requirements

for the degree of

Master of Applied Science

at

Massey University
New Zealand

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1999

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 O₂ and CO₂ 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 O₂ and elevation of internal CO₂ 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 CO₂ were less marked than those of temperature.

In non-coated fruit, the magnitude of decline in internal O₂ was slightly greater than the increase in internal CO₂ 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 CO₂ than to O₂. Since O₂ diffuses through pores more readily than CO₂, 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 O₂ 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.

Acknowledgements

I gratefully thank my chief supervisor, Professor Nigel Banks for his excellent supervision, understanding, his endless patience, his encouragement and his concern for my personal welfare throughout my study and the past three years. Without him, this work would not have been possible. I owe a great debt to him.

I also would like to express my sincere thanks to Dr. Bruce MacKay, my co-supervisor and Dr. Kate Maguire for their helpful support with the statistical analysis.

I am grateful to Sue Nicholson, Peter Jeffery and Anna Kingsley for their assistance with laboratory experiments and valuable help in developing my computer skills. Thanks are also extended to Jason Bengé, Nancy Chen and many other post-graduate students in Plant Science for their helpful advice and discussion throughout my study.

My special thanks to my parents, brothers, husband and daughter for their love, understanding and encouragement, without which this study would have been impossible.

Table of Contents

Abstract	ii
Acknowledgements	iv
Table of Contents	v
List of Figures	viii
List of symbols and abbreviations	xii
Chapter 1 General Introduction	1
Chapter 2 Literature Review	8
2.1 Introduction.....	8
2.2 Respiration rate of the fruit (r_{CO_2}).....	9
2.2.1 Physiological state.....	10
2.2.2 Temperature effect on the respiration.....	12
2.2.3 O ₂ and CO ₂ effects.....	13
2.3 Skin permeance of the fruit.....	14
2.3.1 Law of diffusion.....	14
2.3.2 The structure of the skin.....	16
2.3.3 Variation in permeance.....	17
2.3.4 Routes for gas exchange through the skin.....	19
2.4 Gas diffusion in fruit flesh.....	20
2.5 Edible coatings.....	23
2.5.1 Types of coating.....	23
2.5.1.1 <i>Lipids and resins</i>	24
2.5.1.2 <i>Polysaccharides</i>	25
2.5.1.3 <i>Proteins</i>	26

2.5.1.4	<i>Composite and bilayer coatings</i>	26
2.5.2	Internal atmosphere of coated fruit	27
2.5.2.1	<i>Type of coating</i>	28
2.5.2.2	<i>Pore blockage</i>	28
2.5.2.3	<i>Relative humidity (RH)</i>	29
2.5.2.4	<i>Temperature</i>	30
Chapter 3	Materials and Methods	33
3.1	Experiment 1	33
3.1.1	Gas measurements and analysis	35
3.1.2	Respiration rate	35
3.1.3	Skin permeance to gases	36
3.2	Experiment 2	36
Chapter 4	Results	41
4.1	Porosity changes	41
4.2	Temperature effect on respiration rate	45
4.2.1	Non-coated fruit	45
4.2.2	Coated fruit	48
4.3	Temperature effect on skin permeance	50
4.3.1	Non-coated fruit	50
4.3.2	Coated fruit	54
4.4	Temperature effects on internal gas composition	57
4.4.1	Non-coated fruit	57
4.4.2	Coated fruit	62
4.5	Respiration and internal CO ₂ vs internal O ₂	65
Chapter 5	Discussion	67

5.1	Porosity	68
5.2	Respiration	69
5.3	Permeance	70
5.4	Internal gases	72
5.5	Conclusions.....	75
References		77

List of Figures

Figure 2.1	Relationship between internal partial pressure of O ₂ ($p_{O_2}^i$) and rate of aerobic respiration and fermentation (Dadzie, 1992).....	10
Figure 2.2	Diagram of changes in respiration rate with time before and after harvest (Watada et al., 1984).....	11
Figure 2.3	Temperature effect on the respiration rate of 'Cox's Orange Pippin' and 'Braeburn' apples (Yeasley et al., 1997).....	12
Figure 2.4	Transport models for lipid membranes. Model 1: porous membrane. Model II: Solubility membrane. Liquid vapour interface indicated by double arrows (Schonherr and Schmidt, 1979).....	18
Figure 3.1A	Canulated fruit for internal atmosphere sampling and porosity measurement.	34
Figure 3.1B	Transverse section of a canulated fruit for internal atmosphere sampling and porosity measurement.....	35
Figure 3.2	System for measuring porosity of cannulated 'Braeburn' apples.....	38
Figure 4.1	A typical plot of pressure changes with time after injecting 5 mL of air into a 'Braeburn' apple.....	41
Figure 4.2	Relationship between porosity and skin permeance to O ₂ of 'Braeburn' apples.	43
Figure 4.3	Variation in porosity and internal O ₂ and CO ₂ of 'Braeburn' apples.	43

Figure 4.4	Variation in porosity of individual 'Braeburn' apple fruit with temperature between 0 and 30°C. Each panel (A, B, C or D) presents data from 10 fruit.....	44
Figure 4.5	Respiration rate of 'Braeburn' apples held at between 0 and 20°C.....	46
Figure 4.6	Respiration rate of 'Braeburn' apples held at between 0 and 30°C.....	47
Figure 4.7	Variation in respiration rate (r_{CO_2} , mol kg ⁻¹ s ⁻¹) of 'Braeburn' apples associated with temperature and A) HPC surface coatings at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times 2% HPC solution, and B) carnauba wax at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times commercial formulation.....	49
Figure 4.8	Changes in skin permeance to A), O ₂ ; and B), CO ₂ ; and relative permeance to C), O ₂ ; and D), CO ₂ of 'Braeburn' apples held at between 0 and 20°C.....	51
Figure 4.9	Predicted relationships between P'_{CO_2} and P'_{O_2} of 'Braeburn' apples held at between 0 and 20°C.....	52
Figure 4.10	Changes in skin permeance to A), O ₂ ; and B), CO ₂ of 'Braeburn' apples held at between 0 and 30°C.....	53
Figure 4.11	Variation in skin permeance to O ₂ (P'_{O_2} , mol s ⁻¹ m ⁻² Pa ⁻¹) of 'Braeburn' apples associated with temperature A) HPC surface coatings at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times 2% HPC solution, and B) carnauba wax at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times commercial formulation.....	55
Figure 4.12	Variation in skin permeance to CO ₂ (P'_{CO_2} , mol s ⁻¹ m ⁻² Pa ⁻¹) of 'Braeburn' apples associated with temperature A) HPC surface coatings at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times 2%	

	HPC solution, and B) carnauba wax at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times commercial formulation.....	56
Figure 4.13	Variation in A, internal O_2 ($p_{O_2}^i$, Pa); and B, internal CO_2 partial pressures ($p_{CO_2}^i$, Pa) of 'Braeburn' apples held at between 0 and 20°C.....	58
Figure 4.14	Variation in A, internal O_2 ($p_{O_2}^i$, Pa); and B, internal CO_2 partial pressures ($p_{CO_2}^i$, Pa) of 'Braeburn' apples held at between 0 and 30°C.....	59
Figure 4.15	Relationships between internal O_2 and CO_2 partial pressures in 'Braeburn' apples held at between 0 and 20°C.	60
Figure 4.16	Relationships between and $P_{O_2}^i$ with A, internal O_2 ($p_{O_2}^i$, Pa); and B, internal CO_2 partial pressures ($p_{CO_2}^i$, Pa) of 'Braeburn' apples held at between 0 and 30°C.	61
Figure 4.17	Variation in internal O_2 partial pressure ($p_{O_2}^i$, Pa) of 'Braeburn' apples associated with temperature A) HPC surface coatings at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times 2% HPC solution, and B) carnauba wax at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times commercial formulation.....	63
Figure 4.18	Variation in internal CO_2 partial pressure ($p_{CO_2}^i$, Pa) of 'Braeburn' apples associated with temperature A) HPC surface coatings at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times 2% HPC solution, and B) carnauba wax at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times commercial formulation.....	64
Figure 4.19	Variation in respiration rate (r_{CO_2} , mol kg ⁻¹ s ⁻¹), internal CO_2 partial pressure ($p_{CO_2}^i$, Pa) of 'Braeburn' apples associated with temperature between 0 to 20°C with HPC surface coatings at 0, 0.2, 0.4, 0.6, 0.8 and 1.0 times 2%	

HPC solution, and carnauba wax at 0, 0.2, 0.4, 0.6, 0.8 and
1.0 times commercial formulation. 66

Figure 5.1 Schematic diagram for the effects of temperature and
surface coatngs on gas exchange and internal O₂ and CO₂.
Arrow thickness is proportional to the magnitude of effect
on permeance..... 67

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 analogous 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 ($\text{mol s}^{-1} \text{m m}^{-2} \text{Pa}^{-1}$)
P'_j	=	permeance to gas j ($\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$)
$P'_j{}^{fruit}$	=	skin permeance of fruit to gas j ($\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$)
$P'_j{}^{comb.}$	=	combined permeance of skin and coating to gas j ($\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$)
$P'_j{}^{coat}$	=	permeance of a coating barrier ($\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$)
P_{CO_2}	=	permeance to CO_2 ($\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$)
P_{O_2}	=	permeance to O_2 ($\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$)
\bar{P}^{skin}	=	porosity of the fruit skin ($\text{mol s}^{-1} \text{m}^{-2} \text{Pa}^{-1}$)
Q_{10}	=	temperature quotient for respiration
R	=	gas constant ($8.3134 \text{ m}^3 \text{ Pa mol}^{-1} \text{ K}^{-1}$)
R^2	=	square of the correlation coefficient (r), or proportion of the total variability in the y -values that can be accounted for by the independent variable x .
r_j	=	specific rate of transfer of gas j between internal and external atmospheres ($\text{mol kg}^{-1} \text{ s}^{-1}$)
r_{CO_2}	=	specific rate of transfer of CO_2 between internal and external atmospheres ($\text{mol kg}^{-1} \text{ s}^{-1}$)
$r_{\text{O}_2}^T$	=	respiration rate at $T^\circ\text{C}$ ($\text{mol kg}^{-1} \text{ s}^{-1}$)
$r_{\text{O}_2}^{\text{max},0}$	=	r_{O_2} at 0°C when oxygen is non-limiting ($\text{mol kg}^{-1} \text{ s}^{-1}$)
$r_{\text{O}_2}^{\text{max},T}$	=	inherent maximum r_{O_2} at $T^\circ\text{C}$ when oxygen is non- limiting ($\text{mol kg}^{-1} \text{ s}^{-1}$)
RH	=	relative humidity
RQ^∞	=	respiratory quotient when O_2 is non-limiting.
$S_{j,k}$	=	solubility coefficient of j in medium k ($\text{mol m}^{-3} \text{Pa}^{-1}$)
t	=	time (s)
T	=	temperature ($^\circ\text{C}$)

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

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